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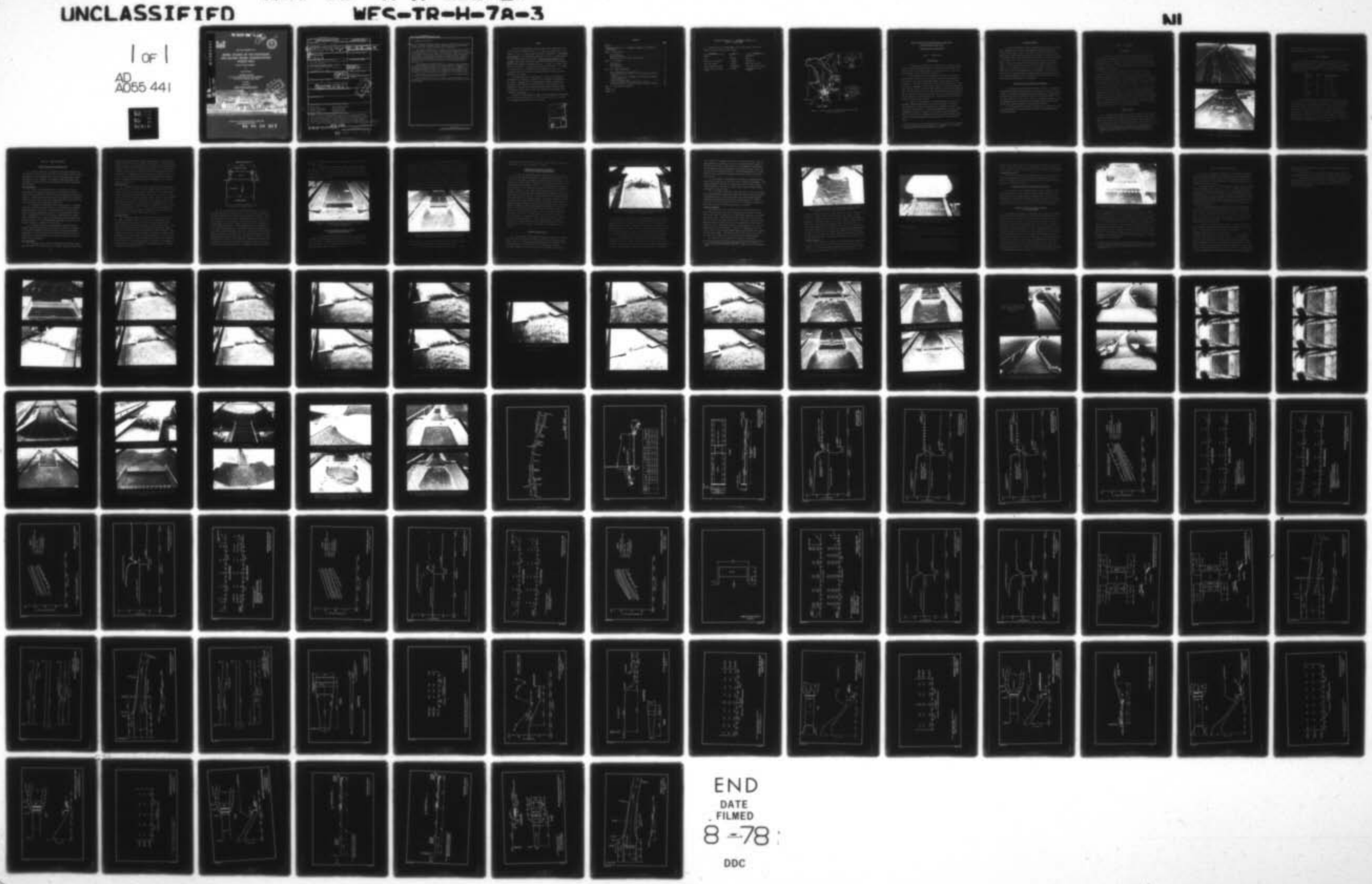

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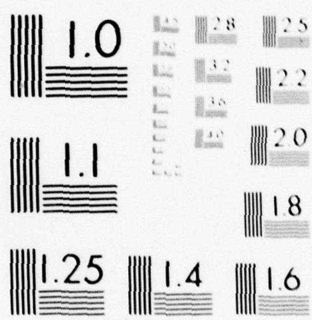

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TECHNICAL REPORT H-78-3

MODEL STUDIES OF THE PORTUGUES AND BUCANA RIVERS CHANNELIZATION PUERTO RICO

Hydraulic Model Investigation

by

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May 1978

Final Report

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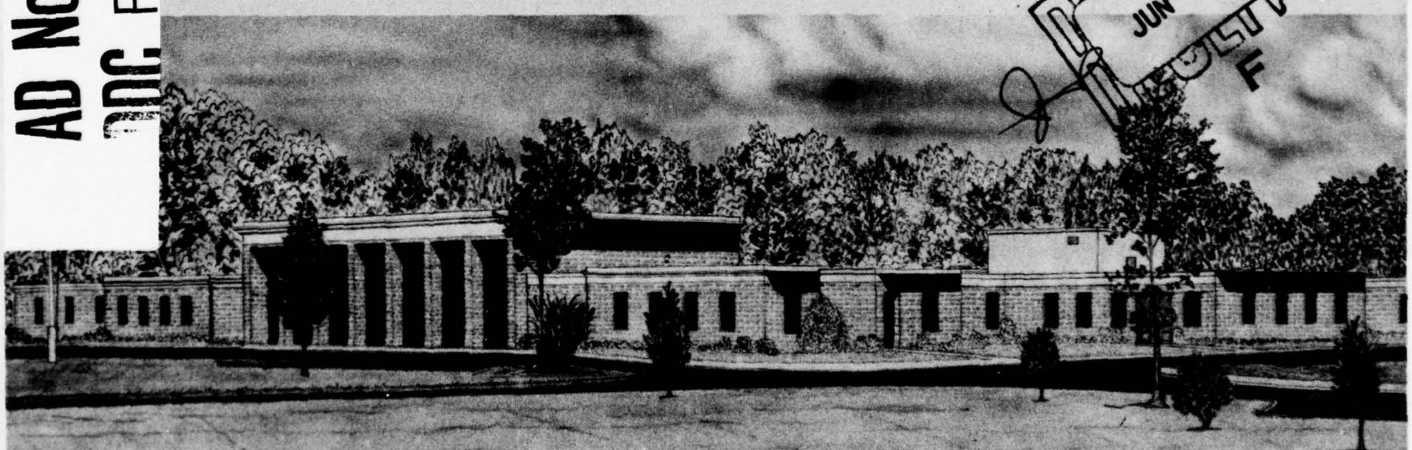

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ABSTRACT

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Two 1:30-scale physical hydraulic models of the Portugues and Bucana Rivers were used to determine the adequacy of the original designs for the flood control channelization project through the city of Ponce, Puerto Rico. The proposed channelization included trapezoidal to rectangular channel transitions, stilling basins, and drop structures in the high-velocity channels. A 3300-ft (prototype) channel length was used to study the transitions

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20. ABSTRACT (Continued)

and stilling basins including riprap stability downstream from the stilling basins. A 1200-ft (prototype) channel length was used to study the drop structures and the adjacent riprap protection requirements.

Test results indicated that the original design with certain modifications would effectively transmit all expected flood releases from the proposed Portugues and Cerrillos Dams. Modifications to transitions at entrances to the high-velocity channel reaches were streamlined within the original right-of-way to reduce surface turbulence and standing waves. Geometry of the original stilling basins was altered to prevent the oblique hydraulic jumps and the end-sill heights were lowered to reduce the water-surface drawdown, surface roller waves, and high bottom velocities downstream of each basin.

ABSTRACT

The original design Bucana Channel drop structures were recommended for the prototype because the preventive measures required to eliminate the tendency for eddying near design flows created additional problems and cost. Two riprap plans were developed for the four Bucana drop structures with design flows of 24,700 to 27,800 cfs. Satisfactory riprap plans were also developed for the exit channel reaches downstream of each stilling basin.

Modification to the Portugues stilling basins were recommended based on the results of the Bucana stilling basin test.

After completion of these tests, certain right-of-way changes in the prototype were realized that could alter the location and design of the structures studied.

PREFACE

The model investigations reported herein were authorized by the Office, Chief of Engineers (OCE), U. S. Army, on 29 April 1974, at the request of the U. S. Army Engineer District, Jacksonville. The studies were conducted in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES), during the period March 1975 to November 1975, under the general supervision of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Structures Division. The tests were conducted by Messrs. N. R. Oswalt, H. H. Allen, and W. A. Walker under the supervision of Mr. G. A. Pickering, Chief of the Locks and Conduits Branch. This report was prepared by Mr. Oswalt.

Mr. Sam Powell of OCE; COL Emmett C. Lee, District Engineer, Jacksonville, COL Donald A. Wisdom, District Engineer, Jacksonville, Mr. James L. Garland, Chief of Engineering Division, Jacksonville, and Messrs. Bill Robinson, Charlie Osborne, and Bob Bullock of the Jacksonville District visited WES during the study to observe model performance, discuss test results, and correlate these results with concurrent design work.

Directors of WES during the study and the preparation and publication of this report were COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
feet per second	0.3048	metres per second
cubic feet per second	0.02831685	cubic metres per second
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

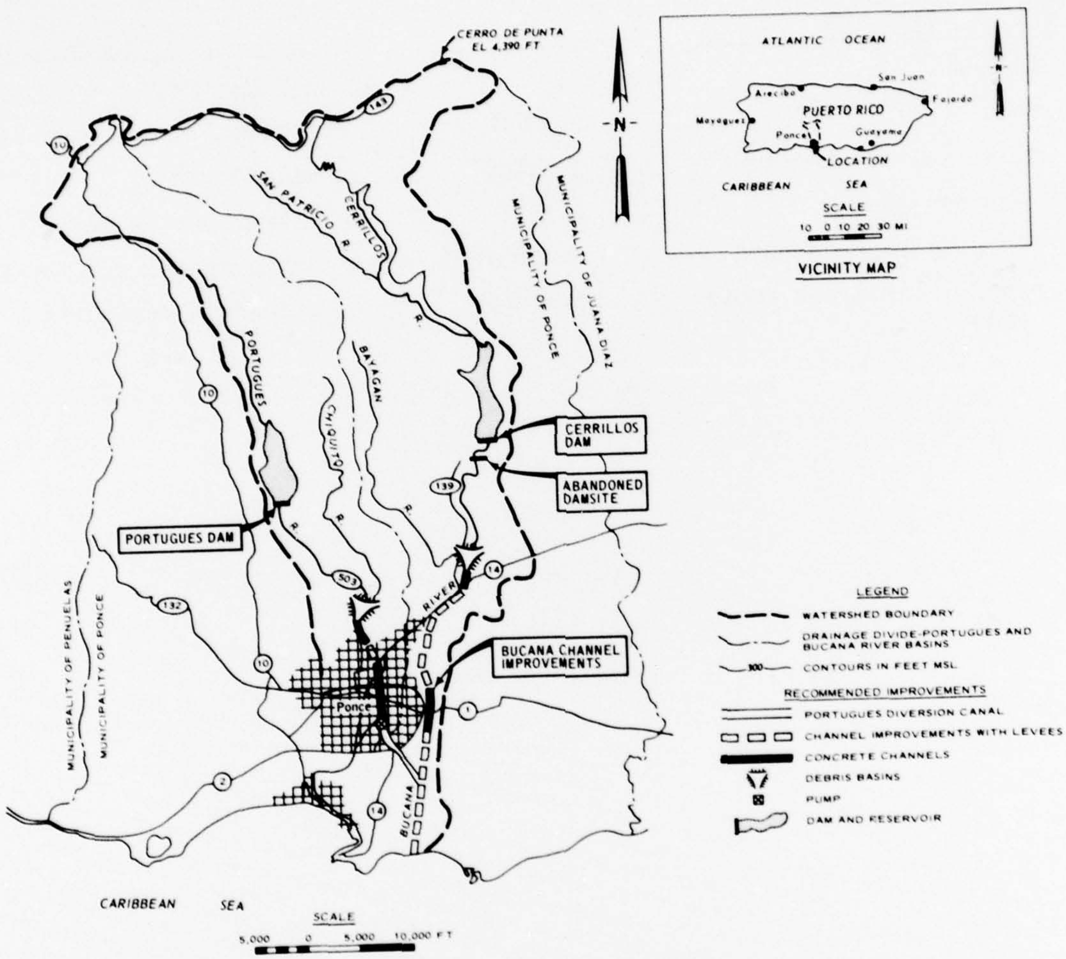

Figure 1. Project plan, recommended flood control plan for Ponce, Puerto Rico

MODEL STUDIES OF THE PORTUGUES AND BUCANA RIVERS CHANNELIZATION, PUERTO RICO

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. Portugues and Bucana Rivers originate on the southern slopes of the Cordillera Central Mountains in Puerto Rico and flow from this central ridge of the island south to the Caribbean Sea at Ponce, the second largest city in Puerto Rico (Figure 1).

2. The authorized plan of improvement consists of two multipurpose lakes, diversion of the Portugues River to the Bucana River in the city of Ponce, and channel improvements on both rivers as shown in Figure 1. The plan would provide essentially standard project flood protection, a dependable surface-water supply for Ponce and surrounding area, and full public use of the recreational facilities surrounding the lake. The dams would be rock-filled, with uncontrolled overflow spillways located in the saddle on the east side of the Cerrillos Dam and in the west abutment of the Portugues Dam. Outlet works would include an intake tower and outlet conduit.

3. There are no provisions for maintaining any flow in the old Portugues Channel downstream of the diversion channel. The lakes are referred to as Lago de Portugues (Lake Portugues) and Lago de Cerrillos (Lake Cerrillos). The channel improvements in Ponce include enlargement of about 5.7 miles* of the Bucana River; enlargement of about 2.1 miles of the Portugues River; and a diversion channel about 1.3 miles in length connecting Portugues River to the lower Bucana River.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

Existing Problems

4. The flood problem in Ponce is among the most serious in Puerto Rico. Damaging floods occur almost annually and severe floods are expected about every 5 years. The flood of October 1970 was the last major flood of known significance until that caused by Hurricane Eloise in September 1975, during this model-testing period. More than 6000 persons in Puerto Rico (1500 in Ponce) were reported driven from their homes; and at least seven deaths and extensive damage resulted from Eloise. Of more significance than loss of property is the threat to human life. During major floods, the entire coastal portion of the basin from Ponce to the Caribbean Sea is inundated. In some areas of Ponce, depth of flooding during a standard project flood would exceed 6 ft. Advance warning of such a flood could be as little as 4 hr, thus precluding safe evacuation of the populace.

Purpose and Scope of Model Investigation

5. Two models were considered necessary to verify the adequacy of and develop desirable modifications to the transitions from the trapezoidal to rectangular Portugues and Bucana Channels, the stilling basins and transitions at the downstream ends of the concrete channels, and the drop structures in the earth channels. One model was used to study the transitions and stilling basins including riprap stability downstream from several Portugues and Bucana Channel basins.

6. The second model was used to study the flow conditions at all drop structures in the Bucana Channel and also one Bucana transition and stilling basin.

PART II: THE MODELS

Description

7. A 1:30-scale model (Figure 2a) reproduced 3300 ft (prototype) of test channel including both trapezoidal and rectangular sections. Initially, this model represented the Bucana Channel between sta 131+20 and 164+00 (Plate 1); and later it was used as a typical channel reach to study the transitions and stilling basins, including riprap stability downstream from the basins.

8. The second model (Figure 2b) was also constructed to a 1:30 scale and reproduced about 1200 ft of the 150-ft-wide Bucana Channel for studying the drop structures and the adjacent riprap protection requirements (Plate 2). The trapezoidal sections of both models were molded in sand and cement mortar to sheet-metal templates initially to test the original structures within the channel. All transitions, stilling basins, rectangular channel sections, and drop structures were made of plastic-coated plywood and some sheet metal. Riprap replaced the cement mortar in later tests to determine the riprap protection requirements with the recommended structures. Filter cloth was placed between the sand and the graded riprap for all riprap tests. The gradations of riprap simulated and tested in the model compare with those based on Engineer Technical Letter 1110-2-120* for 165 lb/cu ft riprap placed in the dry with a 1.0 D_{100} maximum thickness.

Appurtenances

9. Discharges were measured with venturi meters; water-surface elevations and sand and riprap scour depths were obtained with point gages; and velocities were measured with a pitot tube. Steel rails set to grade along the sides of the flume provided a reference plane for

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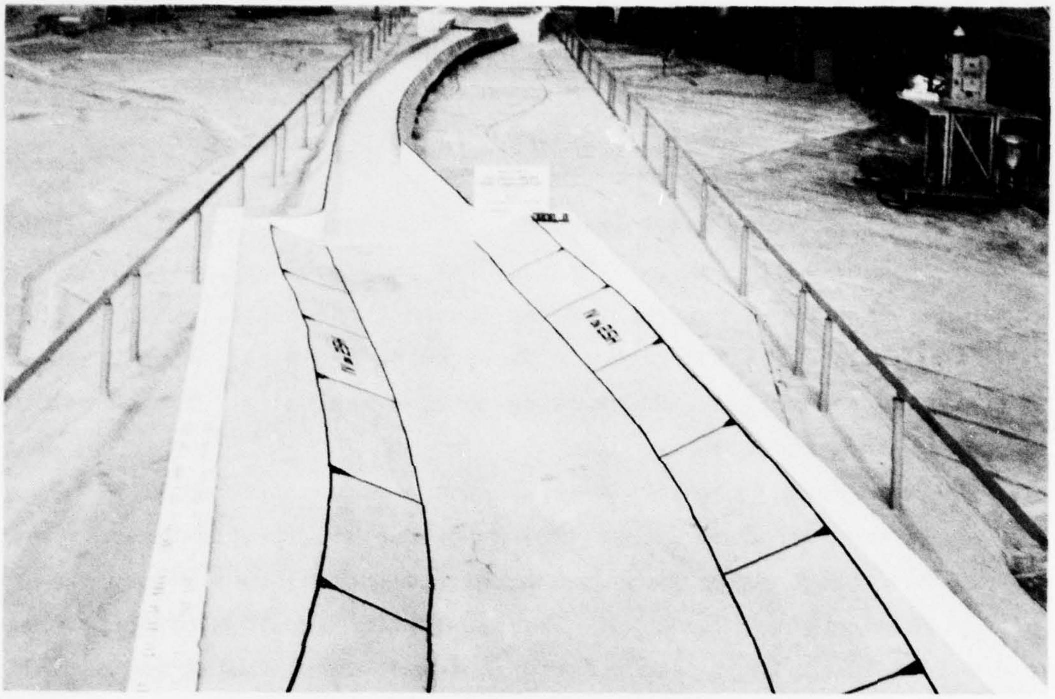
* Office, Chief of Engineers, Department of the Army, "Additional Guidance for Riprap Channel Protection," Engineer Technical Letter 1110-2-120, Incl 1 (page 3 of 7), 14 May 1971, Washington, D. C.



a. 3300-ft test channel

b. Drop structures

Figure 2. Bucana Channel test facility

measuring devices. Tailwater elevations were regulated by means of a gate at the downstream end of the flume.

Scale Relations

10. The accepted equations of hydraulic similitude, based on Froudian relations, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations for transference of model data to prototype equivalents are as follows:

Dimension	Ratio	Scale Relations
Length	L	$L_R = 1:30$
Area	L_R^2	$A_R = 1:900$
Velocity	$L_R^{1/2}$	$V_R = 1:5.477$
Time	$L_R^{1/2}$	$T_R = 1:5.477$
Discharge	$L_R^{5/2}$	$Q_R = 1:4,929.50$
Weight	L_R^3	$W_R = 1:27,000$

11. Model measurements of discharge, water-surface elevations, and velocities can be transferred quantitatively to prototype equivalents by means of the preceding scale relations. Also, the limited experimental data available indicate that the prototype-to-model scale ratio is valid for scaling riprap in the sizes used in this investigation. Evidences of sand scour, however, are considered only qualitatively reliable, since it is not yet possible to reproduce quantitatively in a model the same ratio of flow depth to the diameter of bed material representative of the prototype.

PART III: TESTS AND RESULTS

Bucana Channel Drop Structures 1-4

12. Tests to determine the adequacy of the Bucana Channel drop structures 1-4 (Plate 2) were conducted in the facility shown in Plate 3 and Figure 2b. For expediency, the initial test channel was covered with grout in lieu of riprap. The channel riprap requirements were determined in later tests after the optimum drop structure design had been developed.

Drop structure 1

13. Initial tests conducted with drop structure 1 (Photo 1, Bucana Channel sta 213+20) indicated that a satisfactory hydraulic jump could be maintained in the basin with the design flow of 27,800 cfs (Photo 2). The model water-surface profile and computed water-surface profile along the center line of the channel and 66 ft each side of the center line were in close agreement (Plates 4-6).

14. Performance curves obtained for drop structure 1 throughout the range of expected operation (Plate 7) indicated that the original design structure would provide a satisfactory drop in water surface without increasing downstream velocities or creating adverse flow patterns. Photographs of the flow conditions observed with the design flow of 27,800 cfs and a range of tailwaters beyond those expected are provided in Photo 3. Both upstream and downstream velocities for the original design are provided in Plates 8 and 9.

15. Although satisfactory performance was obtained with the original design, baffle blocks were tested in the basin to determine if they would strengthen the jump and reduce velocities downstream. No improvement to flow conditions was realized with baffle blocks in the relatively short basin; therefore the original design drop structure 1 (Plate 2) was recommended.

Drop structure 2

16. Performance curves obtained throughout the expected range of operation (Plate 10) indicated that the original design structure would

provide a satisfactory drop in water surface without increasing downstream velocities or creating adverse flow patterns. Photos 4a and 4b show performance with the design flow of 24,700 cfs and normal tailwater elevation of 96.5 and a low tailwater elevation of 93.4, respectively. A center-line water-surface profile and velocities measured 15 ft upstream and 75 ft downstream of the structure are provided in Plates 11 and 12. Based on the good performance obtained within the range of expected tailwaters, no modifications were recommended to the original design drop structure 2.

Drop structure 3

17. Performance curves obtained throughout the expected range of operation (Plate 13) indicate that the original design structure 3 would provide a satisfactory drop in water surface without increasing downstream velocities or creating adverse flow patterns. Photos 5a, 5b, and 5c show flow conditions with the design flow of 24,700 cfs and tailwater elevations of 103.2 (forced jump), 104.5 (good jump), and 108.6 (submerged jump), respectively. A center-line water-surface profile and velocities measured 15 ft upstream and 75 ft downstream of the structure are provided in Plates 14 and 15. Based on the good performance obtained within the range of expected tailwaters, no modifications were recommended to the original design drop structure 3.

Drop structure 4

18. Performance curves on drop structure 4 (Plate 16) for the full range of expected flows up to 24,700 cfs indicated that the original design would provide a satisfactory drop in water surface without creating a significant increase in downstream velocities. However, a mild eddy did develop with the normal tailwater and reduced velocities in each side of the drop structure. This intermittent eddy occurred on each side of drop structure 4 as sketched in Figure 3 with tailwaters 0.5 ft or more above the normal tailwater. This created reverse flow, reduced the effective width of drop structure, and created higher velocities in the remaining width of structure. Photographs of good and bad flow conditions with the original design and a discharge of 24,700 cfs are shown in Photo 6.

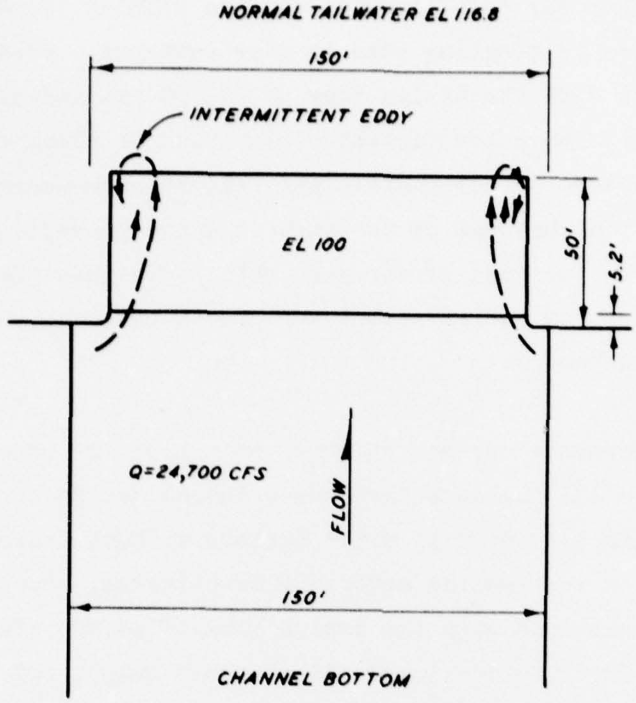


Figure 3. Intermittent eddies in drop structure 4, original design

19. The eddies observed at tailwater elevations of 0.5 ft or more above normal with drop structure 4 (Photo 6b) were attributed to the abrupt approach walls and the related tailwater elevation. Therefore modifications to the original approach walls were tested to prevent occurrence of these eddies. Various semicircular, curved, and straight walls were tested. Design 4, shown in Plate 17, consists of a 35-ft upstream extension of the approach walls on each side with a 15-ft radius at the abutments. This design prevented the eddies and reduced the maximum downstream velocities. A comparison of the original design and design 4 velocities (Plate 18) shows the improved flow distribution and reduced velocities near the invert with design 4. Walls shorter than 35 ft were not as effective in improving flow conditions. Water-surface profiles of the original design and design 4 are shown in Plates 19 and 20, respectively. Photographs of flow conditions with

design 4, a 24,700-cfs design flow, and tailwaters of 116.8 and 119.2 are shown in Photo 7.

20. Unfortunately, the design 4 structure increased hydraulic capacity and approach velocities relative to those with the original drop structure 4, and would require costly additional protection upstream (Figure 4). Therefore the original basin design was favored and recommended for the prototype.

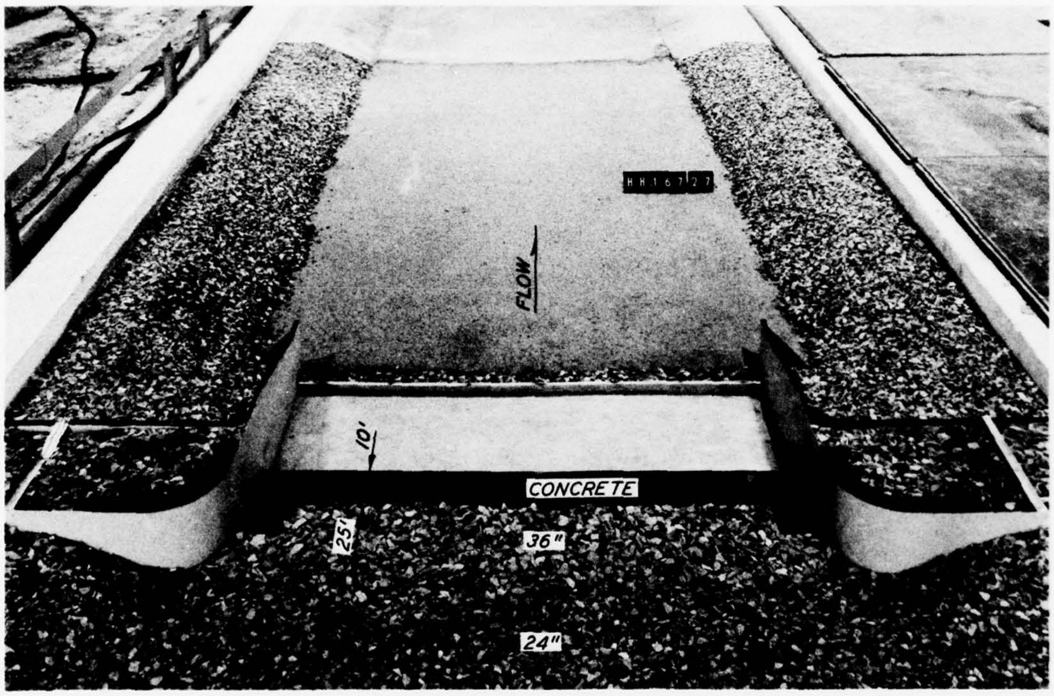


Figure 4. Drop structure 4, design 4, type 1 riprap plan (looking downstream)

Riprap Requirements Adjacent to Drop Structures, Bucana Channel

21. Two riprap plans were developed for the four Bucana drop structures. The largest drop structure (1) with the highest design flow of 27,800 cfs required riprap protection plan 10 (Plate 21). Drop structures 2, 3, and 4 with a design flow of 24,700 cfs required riprap protection plan 8 (Plate 22).

22. The type 8 riprap plan recommended for drop structures 2, 3, and 4 was not recommended for drop structure 1 because the 24-in. riprap upstream of the structure failed as shown in Photo 8. Any appreciable movement of riprap in model tests was considered failure. Some 36-in. riprap upstream of the structure moved after the 24-in. riprap had failed in a previous test; however, a 20-ft-long horizontal blanket of 36-in. riprap plan 10) of the structure was stable (Photo 9). Deposition of model sand and riprap downstream of the upper sill resulted after each test and indicated that maintenance will probably be required after the larger floods for all four drop structures. The deposition of sand and and loose stone in the structure downstream of the upper sill (Figure 5)

Figure 5. Deposits of sand and stone in drop structure 4 after 30-min (prototype) operation with 24,700-cfs flow

did not reduce the structure's performance and is probably typical of deposition to be expected during prototype design flows.

23. Photo 10 shows the recommended riprap design 8 for drop

structure 4 taken after the design flow. This condition is typical of that expected at drop structures 2, 3, and 4.

High-Velocity Channel Alignment and Transitions Design, Bucana Channel

24. Tests in the high-velocity reach of Bucana Channel between sta 164+00 and 131+00 were conducted to determine the adequacy of the original design channel alignment, transition, and stilling basin. Although the original channel retained the design flow of 28,900 cfs within the vertical walls as shown in Photo 11, the turbulence and standing waves generated in the original transition (Photo 12) were improved by design 2 (Plate 23). This modification shortened the transition, remained within the original channel right-of-way, streamlined the flow, and lowered the water surface. A water-surface profile obtained along the center line of the original channel is provided in Plate 24. Tests with the design 2 transition between sta 157+48 and 154+20 indicated improved flow conditions. The entire Bucana Channel water surface between sta 139+00 and 154+00 was lowered an average of 2 ft, and the surface reflected waves were greatly reduced as shown in Photo 13. However, an increase in water level of 2 to 3 ft resulted upstream of the design 2 transition. Modifications to the transition shown in Plate 25, design 3, lowered the water surface upstream and retained the improved flow conditions. Flow conditions with the design 3 transition are shown in Photo 14 and a water-surface profile is provided in Plate 26. The design 3 transition is recommended for the prototype.

Bucana Stilling Basins

25. The original stilling basin produced an irregular or oblique hydraulic jump with flows from 5,000 to 28,900 cfs and expected tailwaters. The toe of the jump was approximately 150 ft upstream of the horizontal apron as shown in Plate 27. Although the inflow was reasonably balanced at the basin entrance (sta 139+40), as shown by

the velocities in Plate 28, an imbalance of flow occurred at the toe of the jump. With the toe of the jump so far upstream (Figure 6), the

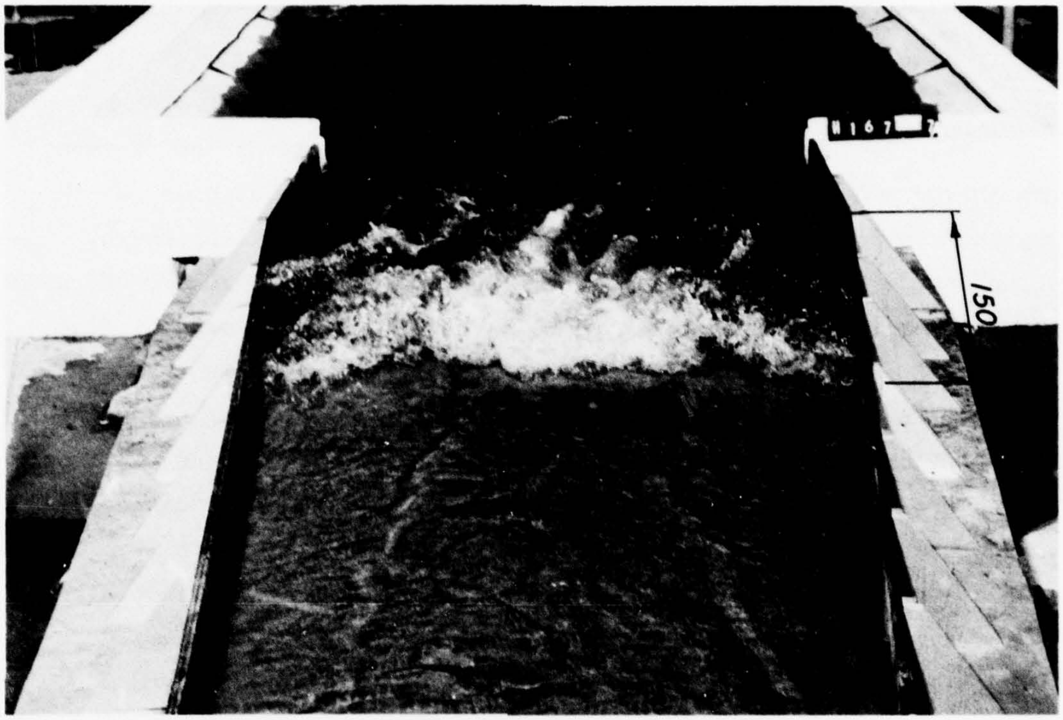


Figure 6. Stilling basin B-1 (original design); design flow 28,900 cfs, tailwater el 28.8

baffle blocks were inefficient and the maximum velocities downstream of the basin (Plate 28) were greater than they would be with a stable hydraulic jump. The original 5.4-ft-high end sill caused excessive drawdown and surface waves downstream from the basin as shown by the water-surface profile in Plate 29. In an effort to improve this condition, the vertical end sill was replaced with a 1V-on-10H upsloping invert, which extended a distance of 54 ft downstream from the basin.

26. It became apparent after several tests that both baffle blocks and a low end sill were essential for good basin performance throughout the entire range of expected flows. Several baffle block sizes and locations were tested, and it was found that 6-ft-high baffles located 45 ft downstream on the horizontal apron with a 3-ft-high end

sill located 90 ft downstream were best for the design flow. This design permitted a reduction of 48 ft in the original 138-ft length of parallel wall section. This, however, did not eliminate eddies with the intermediate and low discharges that allowed the jump to move upstream into the flared wall section. Further improvements in stilling basin B-1 were realized by modifying the invert slope in the flared wall section.

27. The design 5 stilling basin B-1 (Plate 30) produced satisfactory flow conditions for the full range of expected discharges. Good energy dissipation resulted in the basin as shown in Photo 15 with normal tailwaters and flows of 5,000, 10,000, 15,000, 20,000, 25,000, and 28,900 cfs (design flow).

28. A test was conducted to check the effect of the B-1 stilling basin being partially plugged with debris and indicated that a buildup of bed material will occur on the right side of the channel without adversely affecting flow conditions and riprap stability. Figure 7 shows the B-1 stilling basin after 30 min of simulated prototype flow with sand and debris introduced upstream of sta 160+00.

Original design B-2

29. Results of tests conducted with the original designs of Bucana stilling basins B-2 and B-3 indicated the necessity to modify the end sills and the channel bottom immediately downstream to accommodate design flows. The original B-2 and B-3 end sills were vertical and 8.0 ft and 8.3 ft high, respectively. According to the most recent hydraulic design guidance,* the end sill heights for both B-2 and B-3 should be 0.5 D_1. This would yield end sill heights of 2.5 to 3.0 ft. Sloping end sills are preferred to vertical or stepped end sills because of their self-cleaning tendency which reduces damage from trapped rock and other debris. The baffle blocks in both basins are located and sized in accordance with the above-referenced design guidance.

30. Photo 16 of the original B-2 basin was taken before

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* U. S. Army Engineer Waterways Experiment Station, CE, "Report of Hydraulic Design Conferences, 1971-1972," page 6, Dec 1973, Vicksburg, Miss.

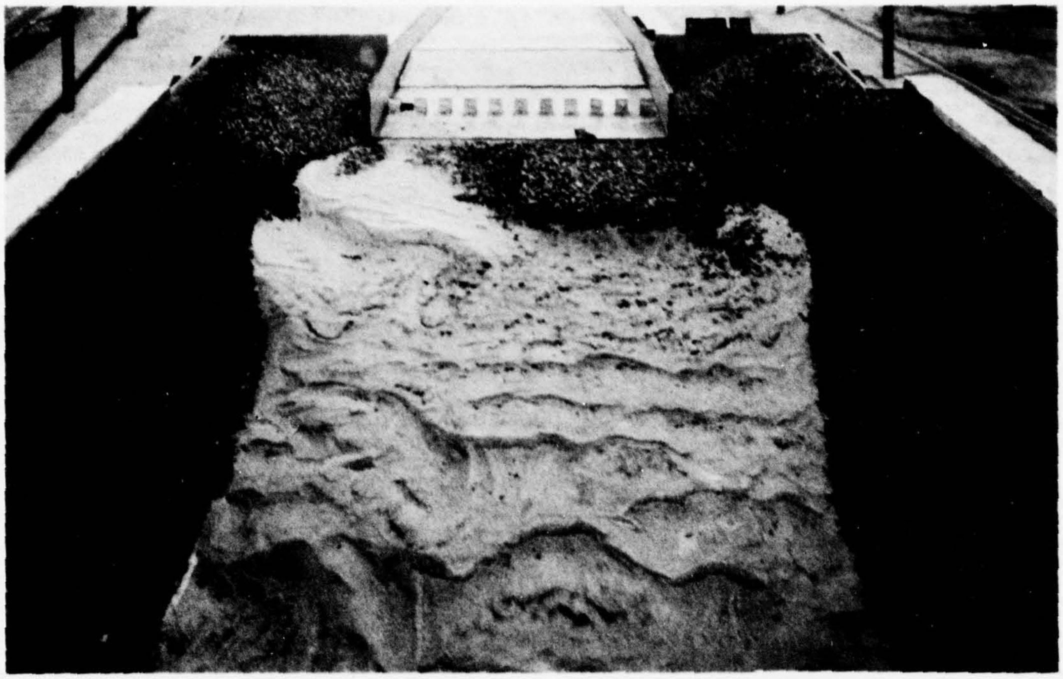

Figure 7. Sand and debris in stilling basin B-1 after 30-min (prototype) operation with design flow 28,900 cfs

operating the model and Photo 17 shows the basin with the design flow of 28,400 cfs. Failure of the original design 24-in. riprap is shown in Photo 18. Lowering the end sill and exit channel as discussed in paragraph 32 prevented movement of the 24-in. riprap. A weak hydraulic jump formed in the basin, although velocities downstream were not equally distributed across the channel (Plate 31). Also, there was a considerable drawdown of the water surface immediately downstream from the end sill (Plate 32). The unequal distribution of velocities was attributed to the transition upstream between sta 188+92.8 and 187+66, and the drawdown in water surface was attributed to the high end sill.

Original design B-3

31. Photo 19 of the original B-3 stilling basin was taken before operation of the model and Photo 20 was taken with the design flow 22,700 cfs. Velocities measured downstream from the basin are shown in Plate 33 and a water-surface profile is shown in Plate 34. The

water surface in the basin was approximately 3 ft higher than that expected and overtopped the basin walls. A drawdown of the water surface immediately downstream from the end sill resulted in failure of the 30-in. riprap as shown in Figure 8.

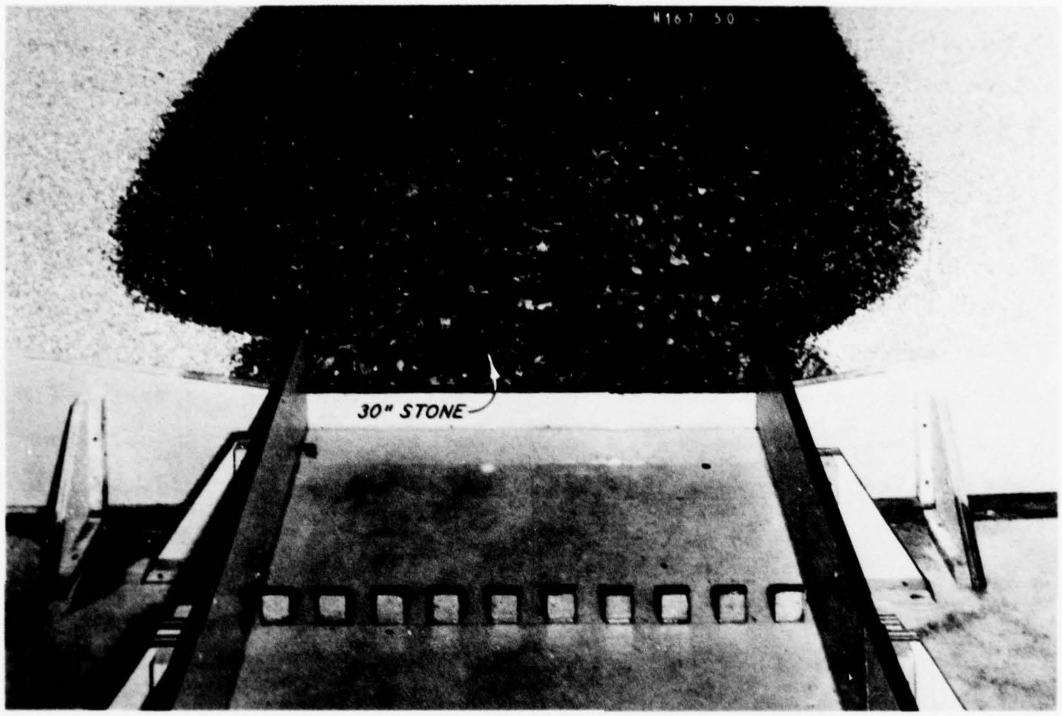

Figure 8. Dry bed of original stilling basin B-3 showing riprap damage after 1-hr (prototype) operation with design flow 22,700 cfs and tailwater el 129.5

Recommended design B-2

32. Basic modifications to both B-2 and B-3 basins were the lowering of both the end sills and exit channels to prevent severe standing waves and high bottom velocities, thereby minimizing the downstream riprap protection.

33. Plate 35 contains the recommended design (type 2) for stilling basin B-2. The 1V-on-10H upslope of sand was tested with slopes up to 1V on 4H without affecting performance at design flow. Whether a 1V-on-4H or a 1V-on-10H slope is used, flows near the design discharge of 28,400 cfs will scour and reshape the initial channel bottom.

Therefore, the least costly bottom slope should be selected for the prototype. The water-surface profile and maximum velocities observed with the recommended B-2 basin are provided in Plates 36 and 37, respectively.

Recommended design B-3

34. Plate 38 contains the recommended design for the B-3 stilling basin. Maximum velocities (Plate 39) and the water-surface profile (Plate 40) observed with the design discharge indicated good performance with the recommended B-3 basin.

Portugues Channel Stilling Basins P-1 and P-2

35. A review of the Portugues Channel stilling basins P-1 and P-2 indicated that the original designs were structurally similar to the Bucana basins; and although the unit discharges were lower, relative modifications could be made for basins P-1 and P-2 based on test results of basins B-1, B-2, and B-3. The proposed modifications for stilling basins P-1 and P-2 are provided in Plates 41 and 42, respectively.

Riprap Protection for Various Reaches of Bucana Channel

36. Tests were conducted to determine the minimum riprap requirements downstream from Bucana stilling basin B-1 and upstream from the transition at sta 157+81. Initial tests were conducted with 18-in. riprap sloped up 1V on 25H to the natural channel invert. Failure of this riprap occurred with the design discharge as shown in Figure 9. The 18-in. riprap was replaced with 24-in. riprap, but again failure occurred with the design discharge. A 30-in. riprap blanket was required to remain stable on the 1V-on-25H upslope downstream of the recommended B-1 basin; however, a 24-in. riprap blanket was adequate protection when placed horizontally at el 11.5 downstream of the recommended basin design shown in Plate 43. This plan is recommended for prototype use. Photo 21 shows the model after 1-hr (prototype) operation with the design flow of 28,900 cfs and indicates that the 18-in. riprap on the side slopes and the 24-in. riprap on the invert will be stable although the natural channel bottom is likely to be scoured as was the model

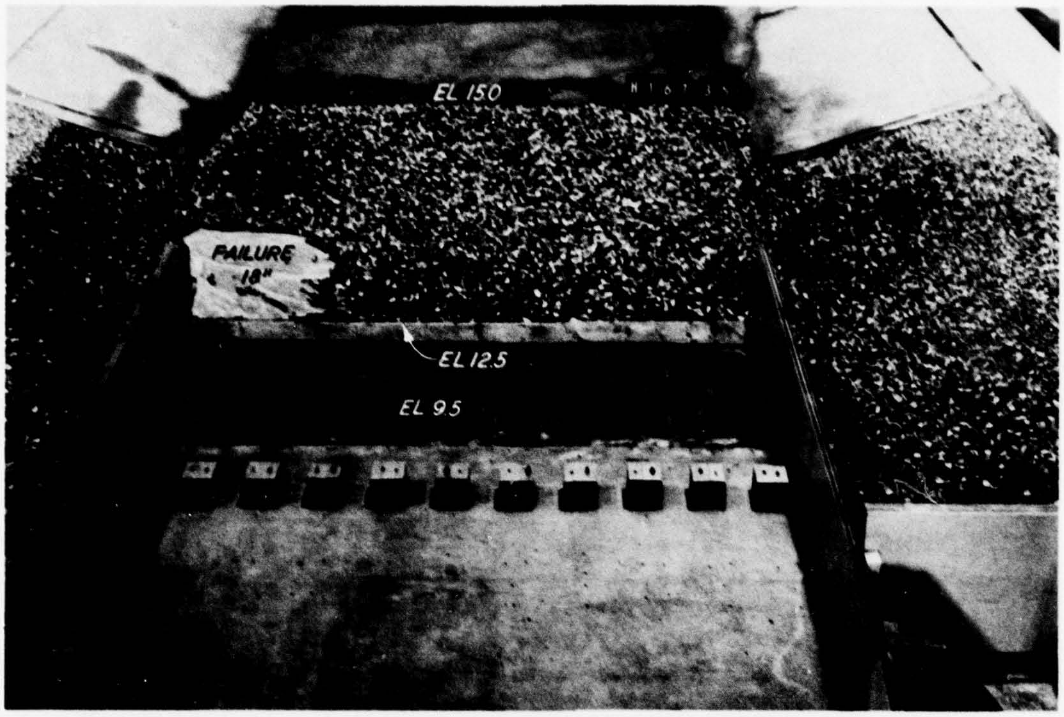

Figure 9. Failure of 18-in. riprap after 30-min (prototype) operation with design flow 28,900 cfs

sand. The revetment toe protection method "A" from Engineer Manual 1110-2-1601,* was used along the bank slopes for a depth of 4 ft below the existing groundline. It is recommended that this method be used in the prototype to protect against possible scour of the natural invert.

37. The original riprap protection upstream of transition design 3 (Plate 44 and Photo 22) was exposed to the design flow for 2 hr (prototype), causing some movement of the sand bottom and loose stone without actual failure or damage to the 18-in. riprap bottom or slopes (Photo 23). The original riprap protection plan (Plate 44) withstood 9-hr additional exposure with 28,900 cfs without damage and is therefore recommended for the prototype.

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* Office, Chief of Engineers, Department of the Army, "Hydraulic Design of Flood Control Channels," Engineer Manual 1110-2-1601, 1 Jul 1970, Washington, D. C.

PART IV: DISCUSSION OF RESULTS

38. Tests to determine the adequacy of the channel improvements on both Bucana and Portugues Rivers indicated that the original design with certain modifications would effectively transmit all expected flood conditions up to the standard project flood and releases from the Portugues and Cerrillos Dams.

39. Eddies tended to occur with tailwaters above normal at design flows with Bucana drop structures 1, 2, and 3. Although mild eddying did develop with Bucana drop structure 4 at normal tailwater and the design flow of 24,700 cfs, the preventive measures to improve the downstream performance increased hydraulic capacity and approach velocities and required more expensive channel protection upstream. Therefore, the original design drop structures 1-4 were favored and recommended for prototype construction.

40. Two riprap plans were developed for the four Bucana drop structures. The largest drop structure (1) with the highest design flow of 27,800 cfs required riprap protection plan 10. Drop structures 2-4 with a design flow of 24,700 cfs required riprap protection plan 8. The deposition of model sand and riprap in the drop structure basin indicated that "clean-out" type maintenance will probably be required after the larger floods.

41. Tests in the high-velocity reach of the Bucana Channel between sta 164+00 and 131+00 indicated surface turbulence and standing waves. Transition modifications (design 3) provided the necessary improvements for the range of expected flows. The original Bucana stilling basins B-1, B-2, and B-3 produced irregular or oblique hydraulic jumps with flows from 5,000 to 28,900 cfs and expected tailwaters. Excessive end-sill heights on all three basin designs caused water-surface drawdown and surface waves downstream from the basins. Eddies within stilling basin B-1 were eliminated by modifying the invert slope and the overall basin dimensions as shown in design 5. The basic modifications recommended for both B-2 and B-3 basins were the lowering of

the end sills and exit channels to prevent severe standing waves and high bottom velocities.

42. Modifications to the Portugues stilling basins P-1 and P-2 were recommended based on the results of the Bucana stilling basin tests.

43. Satisfactory riprap plans were developed for the exit channel reaches downstream of each stilling basin. The minimum riprap protection requirements established were adequate for the full range of expected flows and tailwaters.

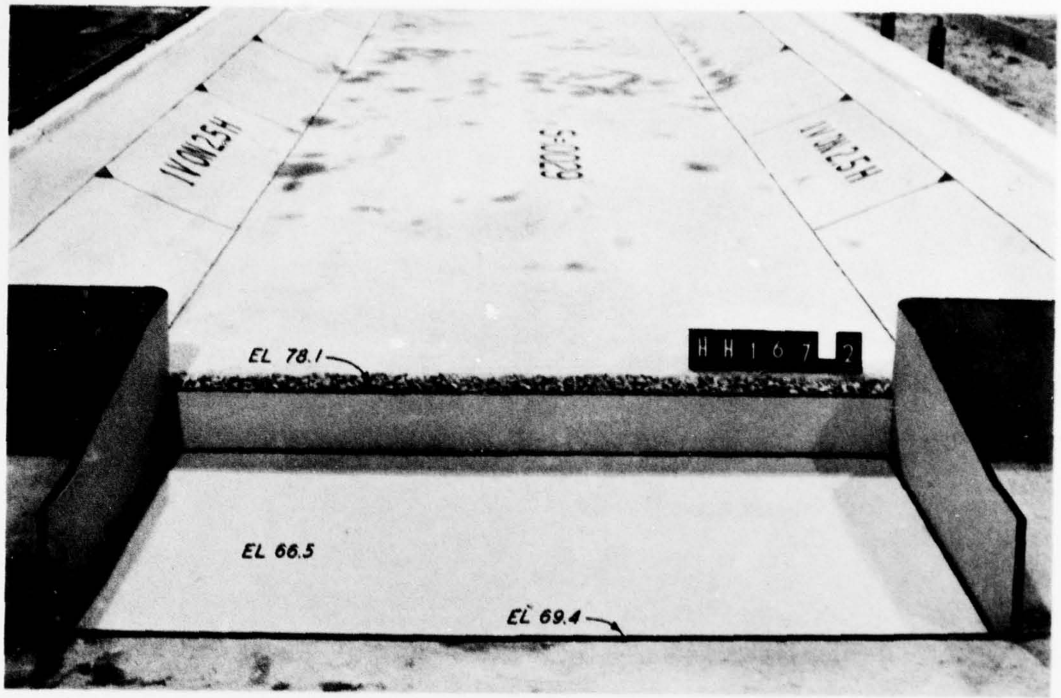
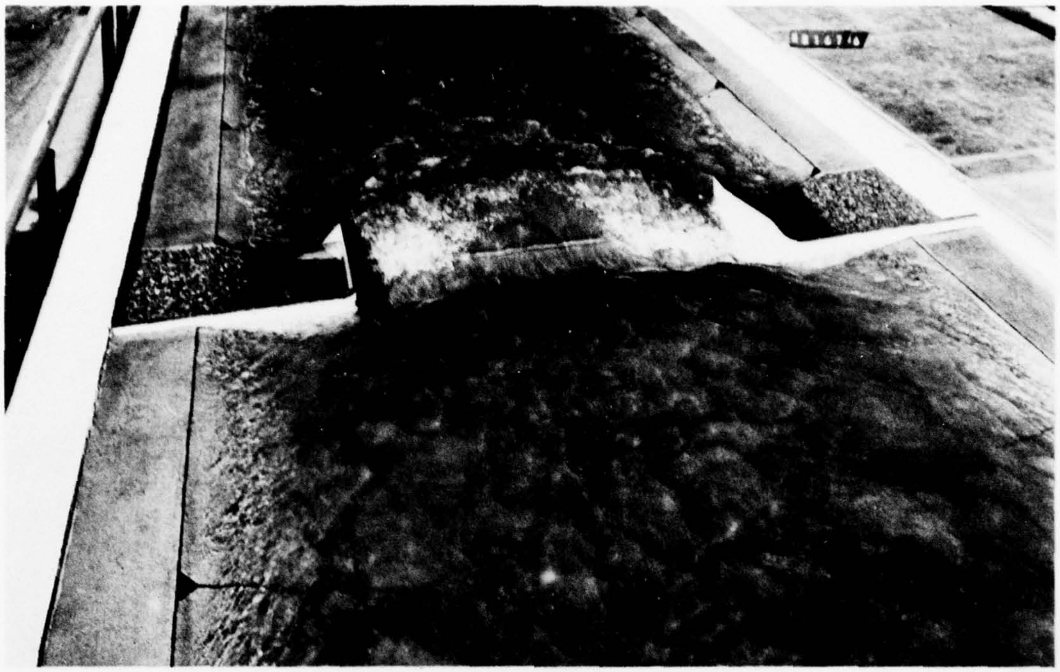
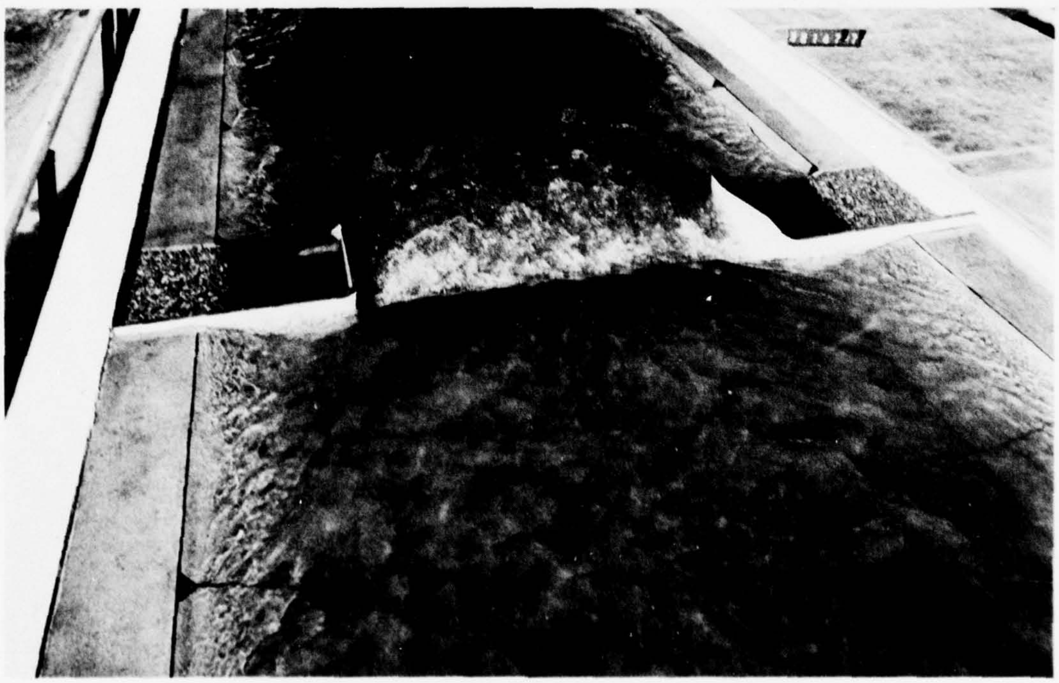


Photo 1. Drop structure 1

Photo 2. Close-up of 27,800-cfs design flow, drop structure 1

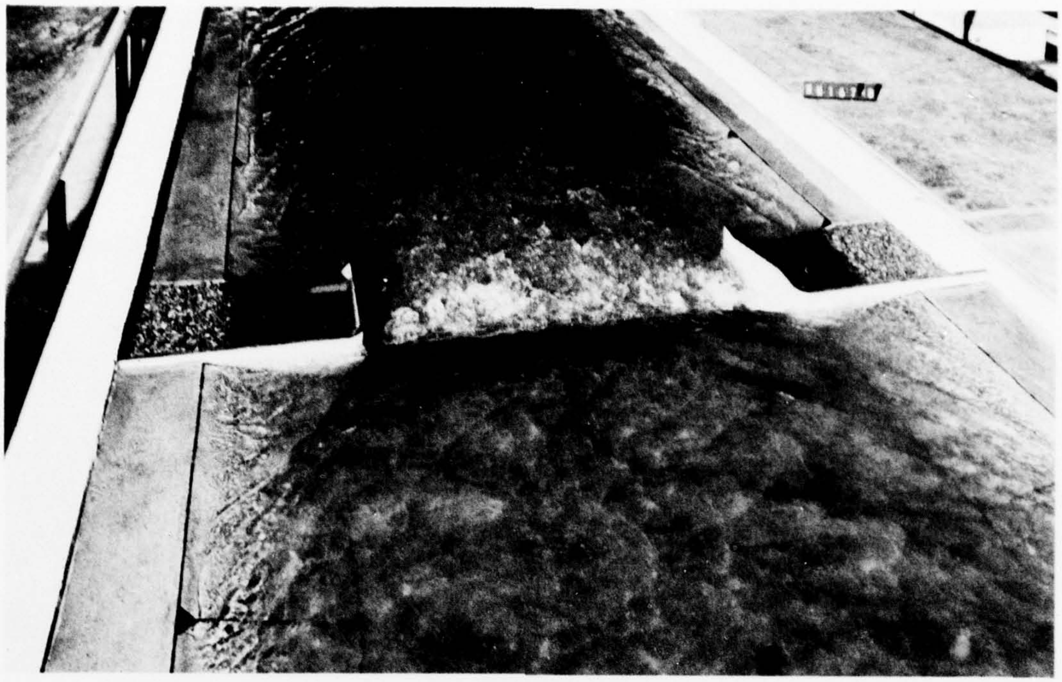


a. Tailwater el 81.2 (1.8 ft below rating curve); hydraulic jump is sweeping out of drop structure

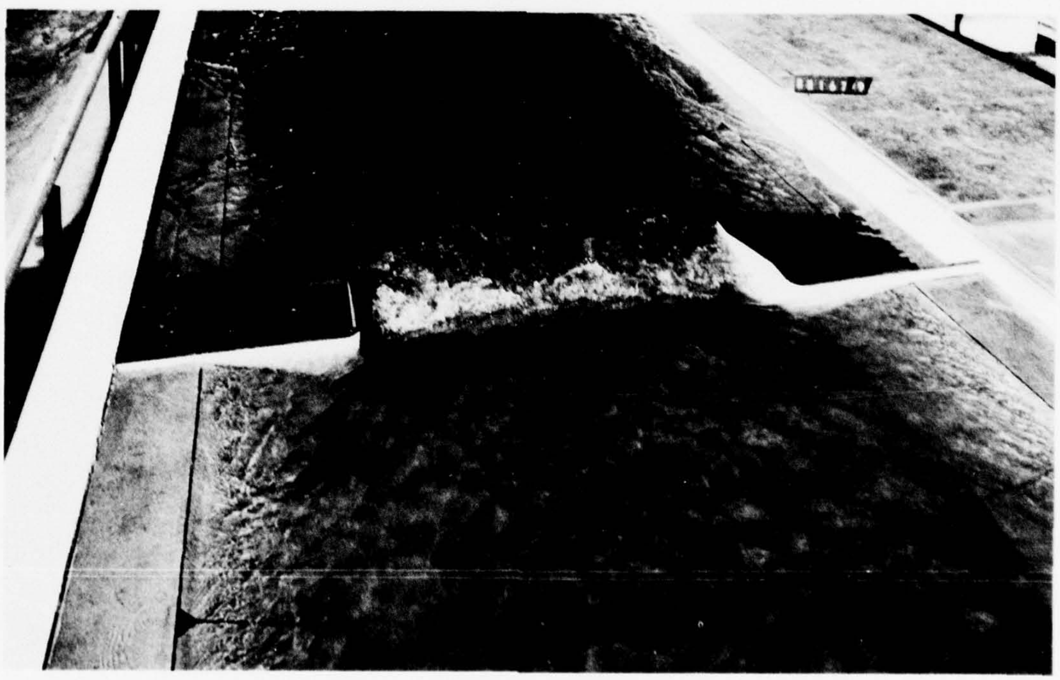


b. Tailwater el 82.1 (0.9 ft below rating curve); forced hydraulic jump

Photo 3. Drop structure 1 (original design), design flow 27,800 cfs (sheet 1 of 2)

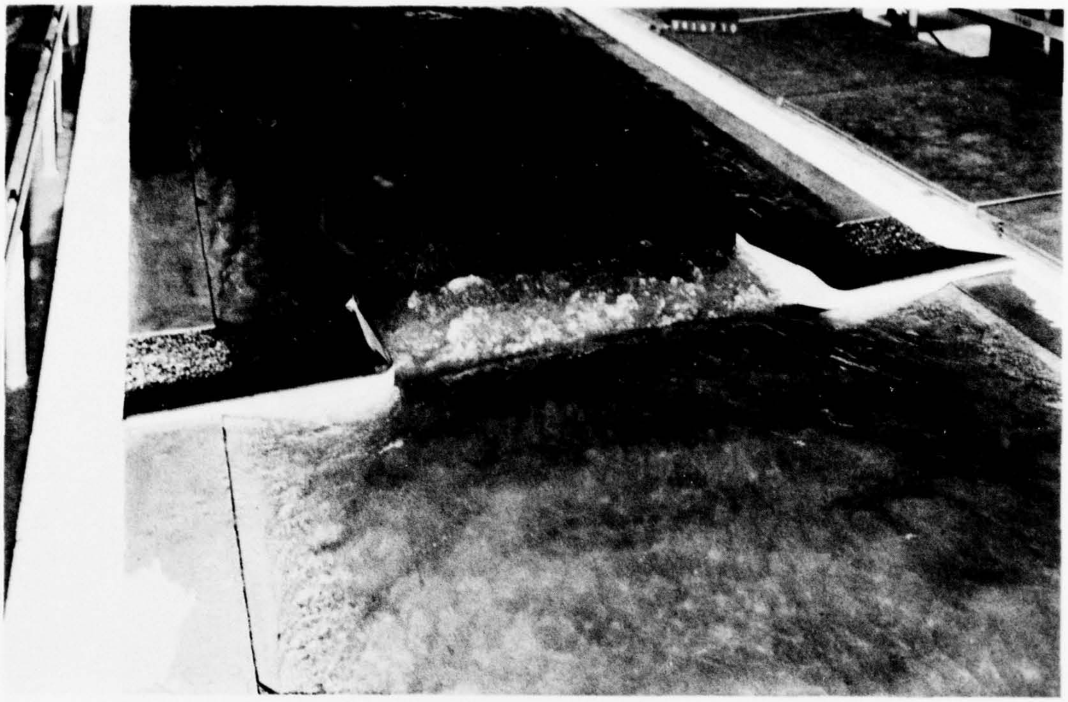


c. Tailwater el 83.7 (0.7 ft above rating curve); good hydraulic jump

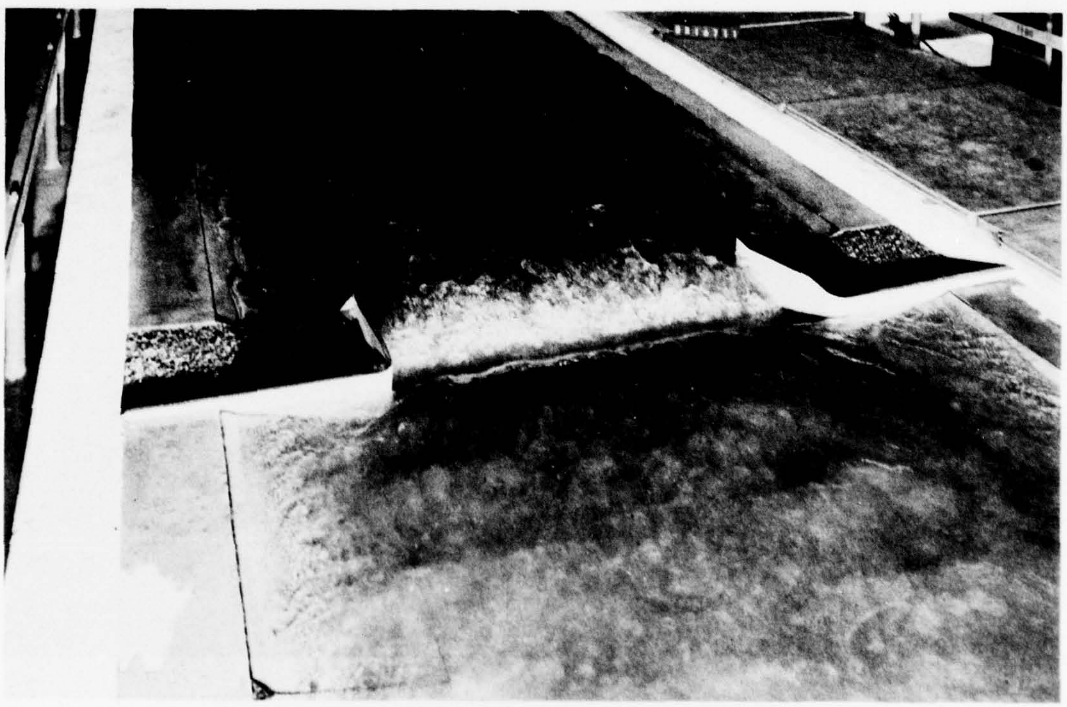


d. Tailwater el 84.5 (1.6 ft above rating curve); mild eddy on each side of drop structure

Photo 3 (sheet 2 of 2)

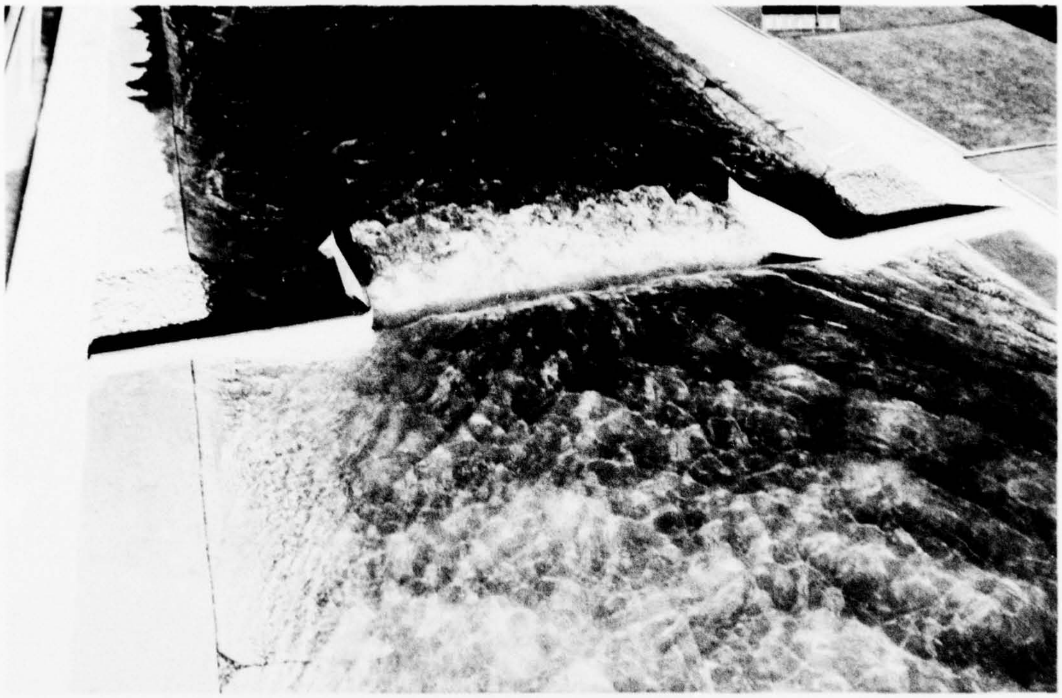


a. Tailwater el 96.5

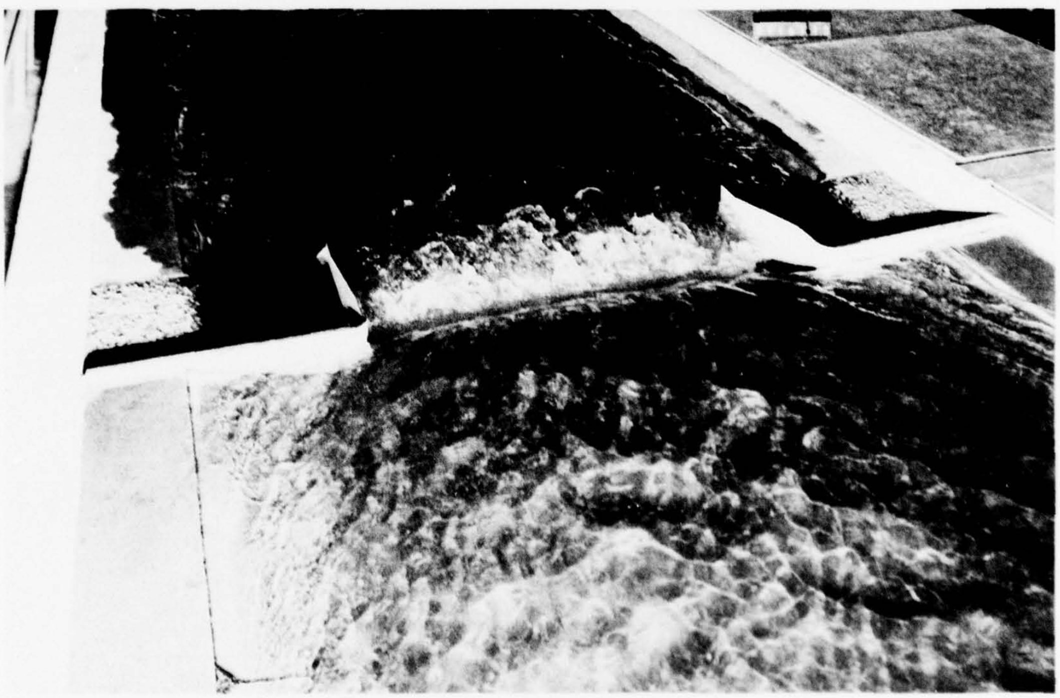


b. Tailwater el 93.4

Photo 4. Drop structure 2, design flow 24,700 cfs

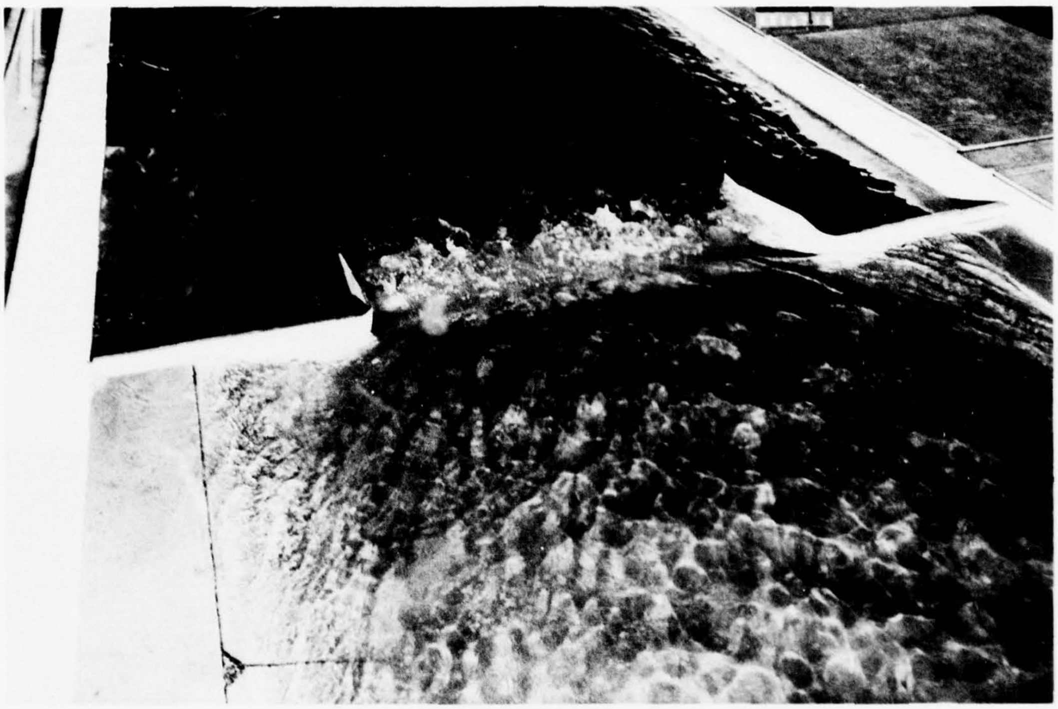


a. Tailwater el 103.2, forced jump



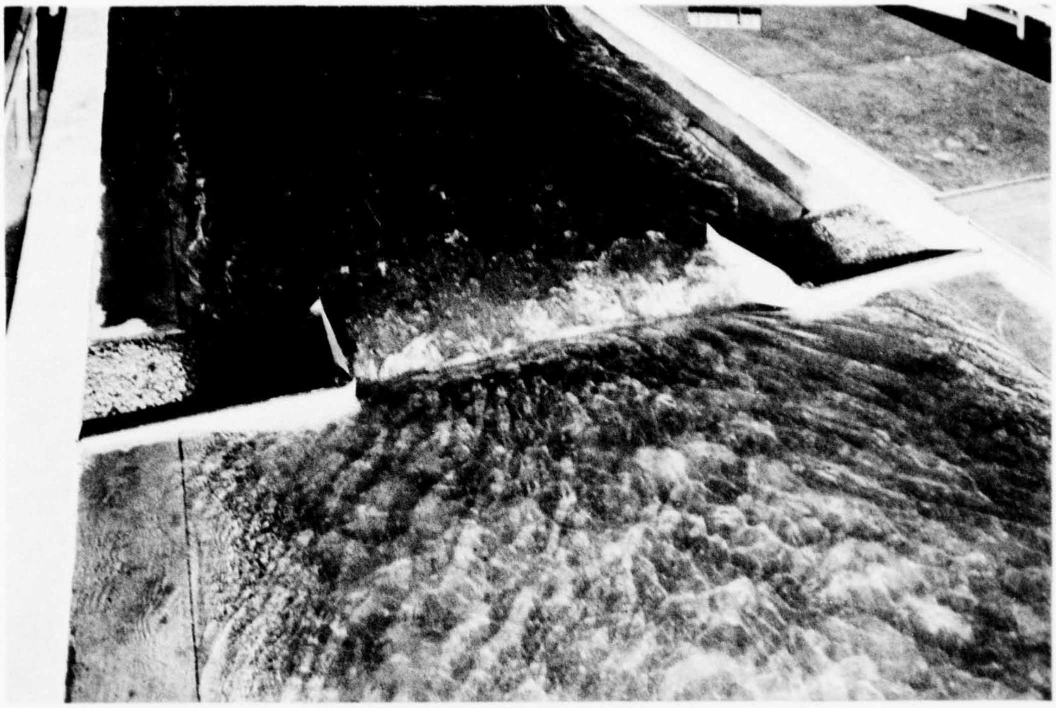
b. Tailwater el 104.5, good jump

Photo 5. Drop structure 3, design flow 24,700 cfs (sheet 1 of 2)

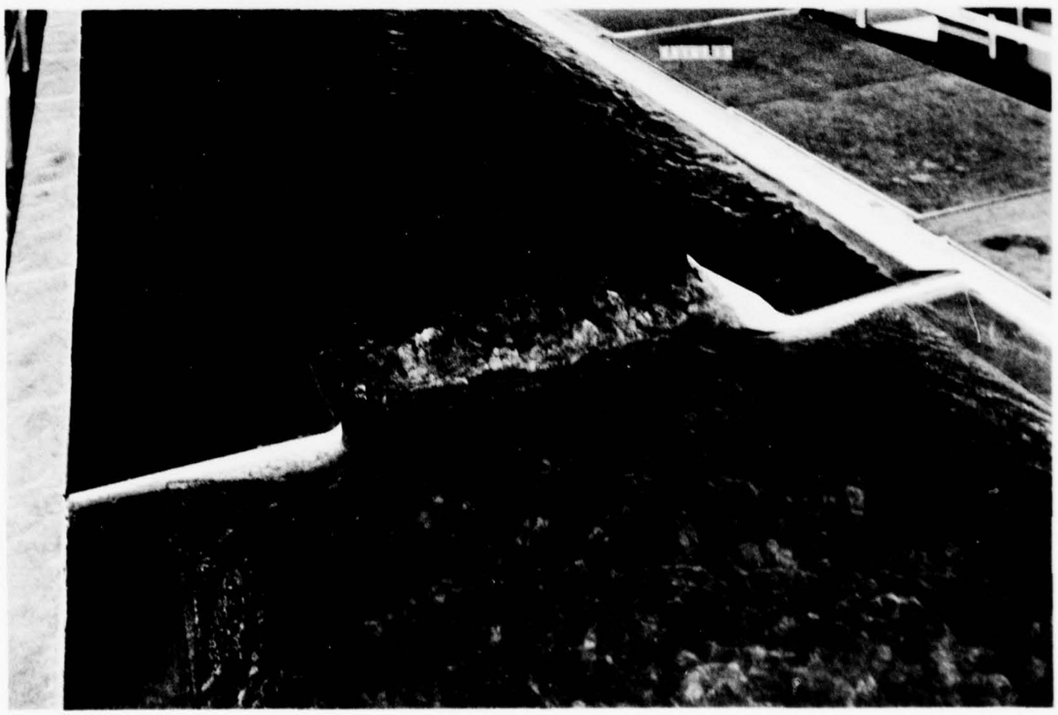


c. Tailwater el 108.6, submerged jump

Photo 5. (sheet 2 of 2)



a. Tailwater el 116.8, good jump



b. Tailwater el, 119.2, eddies

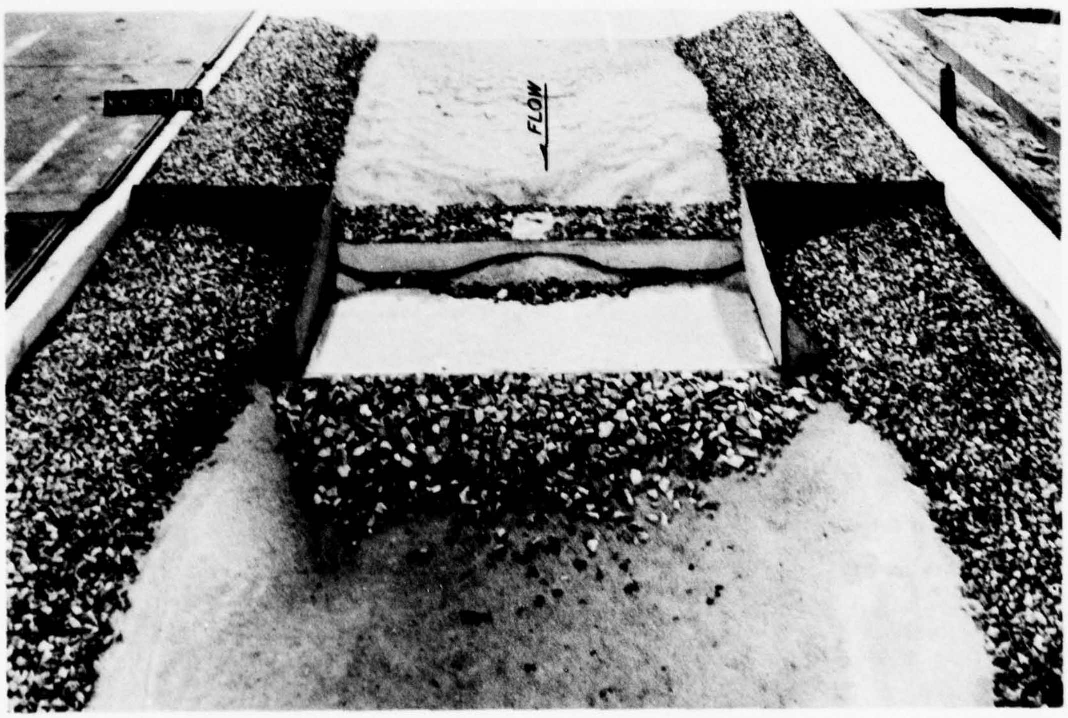
Photo 6. Drop structure 4 (original design), design flow 24,700 cfs

a. Tailwater el 116.8, good jump

b. Tailwater el 119.2, good jump

Photo 7. Drop structure 4 (design 4), design flow 24,700 cfs

a. Looking downstream



b. Looking upstream

Photo 8. Drop structure 1 (original design); failure of type 8 riprap plan after 30-min (prototype) operation with 27,800-cfs flow

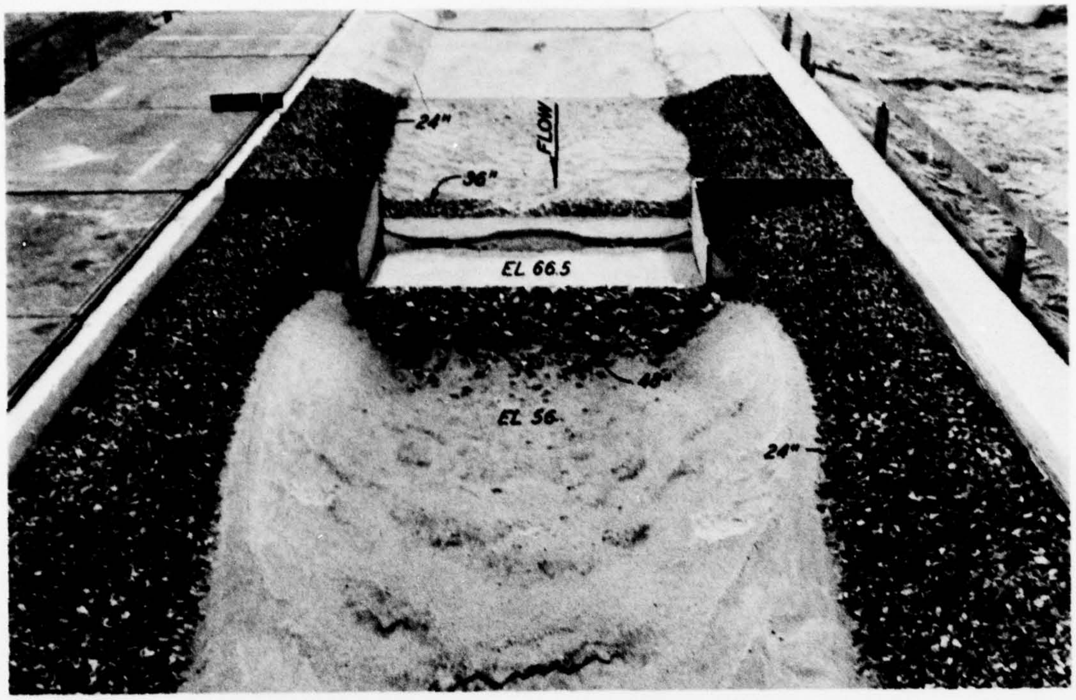


Photo 9. Drop structure 1, type 10 riprap plan (stable); looking upstream after 1-hr (prototype) operation with 27,800-cfs flow

Photo 10. Drop structure 4 (design 4); type 8 riprap plan (recommended) after 1-hr (prototype) operation with 24,700-cfs flow

Photo 11. Overall view of model (Bucana Channel, original design); design flow 28,900 cfs

Photo 12. Bucana Channel original design transition; standing waves at sta 157+81 (looking downstream), design flow 28,900 cfs

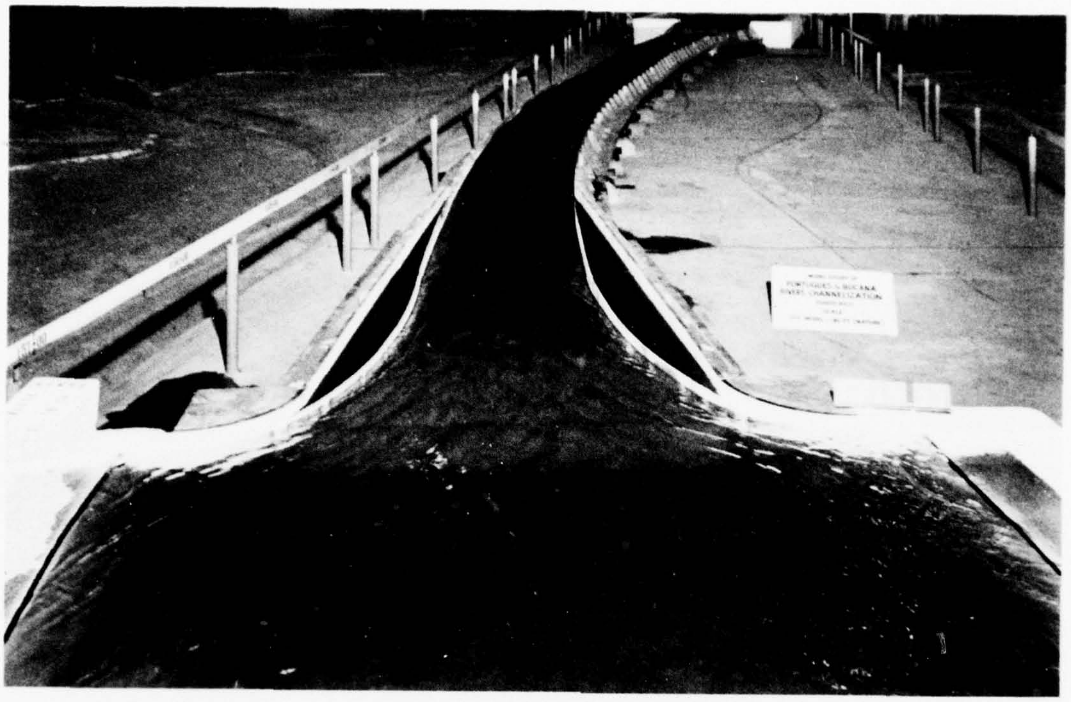


Photo 13. Bucana Channel design 2 transition at sta 157+81; design flow 28,900 cfs, tailwater el 28.8, bottom slope 0.030

Photo 14. Bucana Channel design 3 transition at sta 157+81; design flow 28,900 cfs, bottom slope 0.0514

a. Flow 5,000 cfs
Tailwater el 19.5

b. Flow 10,000 cfs
Tailwater el 22.2

c. Flow 15,000 cfs
Tailwater el 24.5

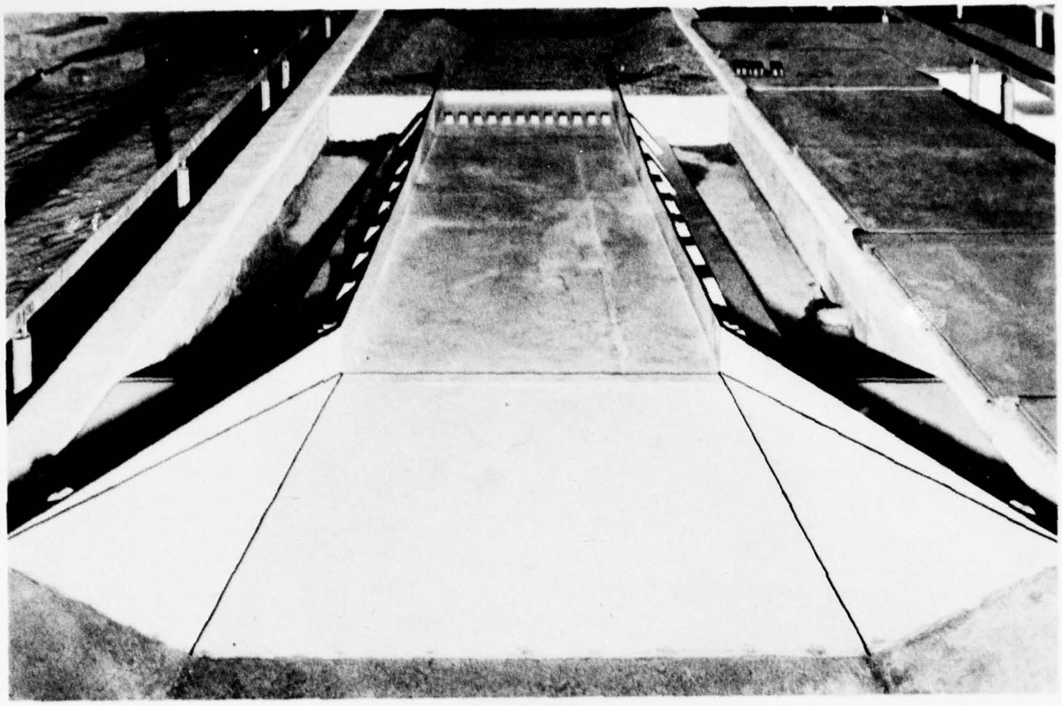
Photo 15. Stilling basin B-1, design 5 (sheet 1 of 2)

d. Flow 20,000 cfs
tailwater el 26.3

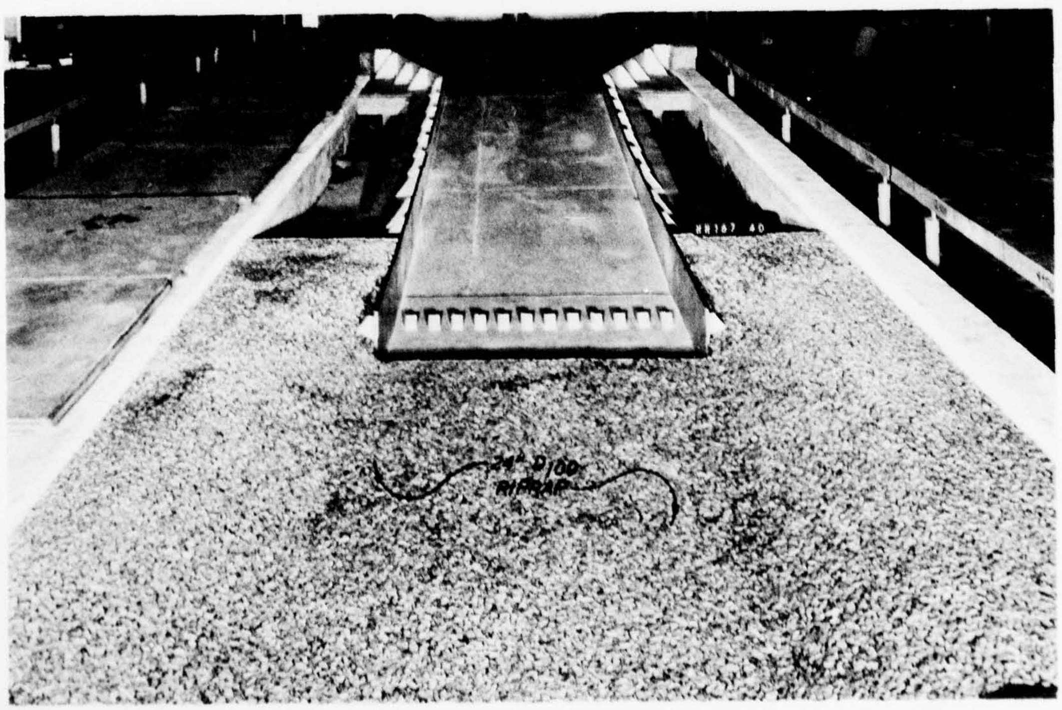
e. Flow 25,000 cfs
Tailwater el 27.9

f. Flow 28,900 cfs
Tailwater el 28.8

Photo 15. (sheet 2 of 2)



a. Looking downstream



b. Looking upstream

Photo 16. Stilling basin B-2 (original design)

Photo 17. Stilling basin B-2 (original design); design flow 28,400 cfs, tailwater el 56.3

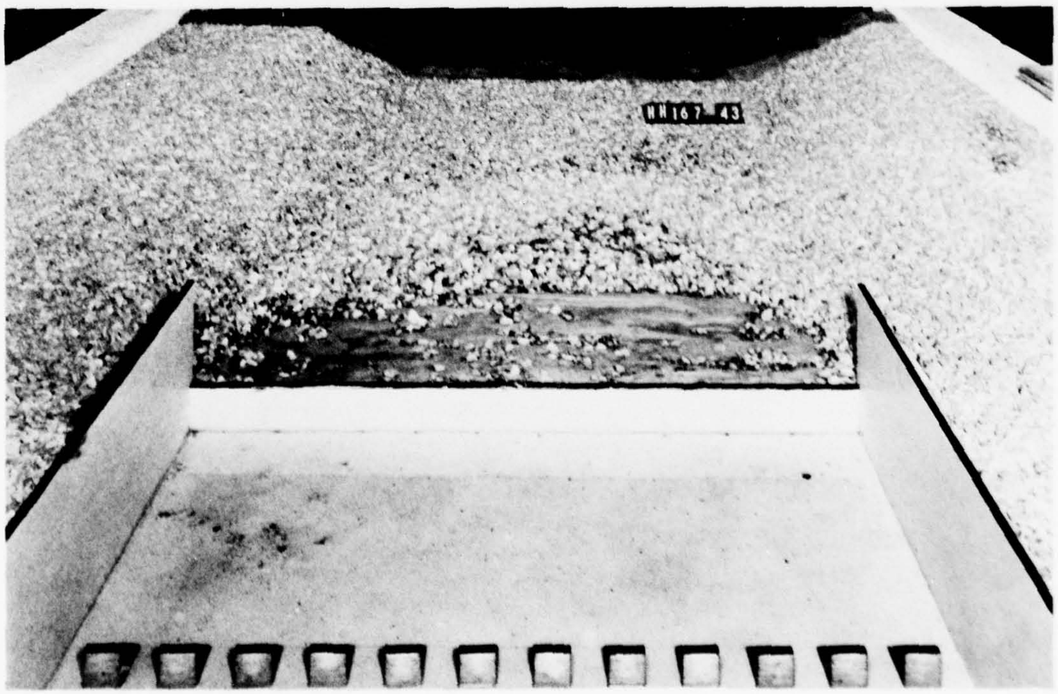
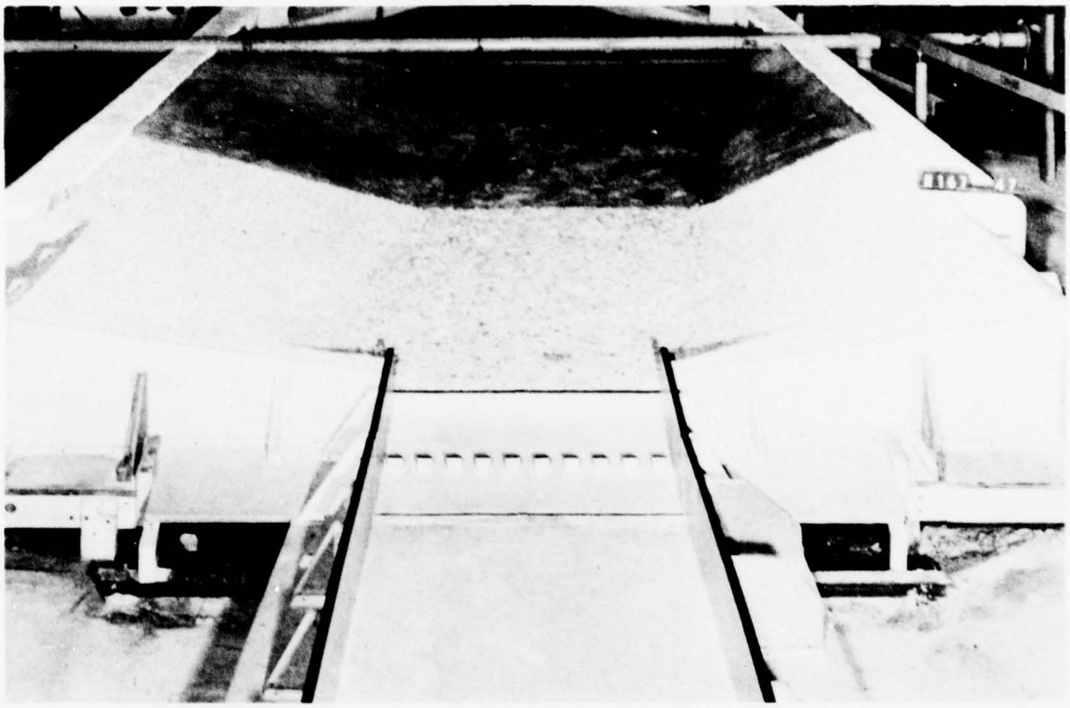


Photo 18. Stilling basin B-2 (original design) showing riprap damage after 1-hr (prototype) operation with design flow 28,400 cfs and tailwater el 56.3



a. Looking downstream

b. Looking upstream

Photo 19. Stilling basin B-3 (original design)

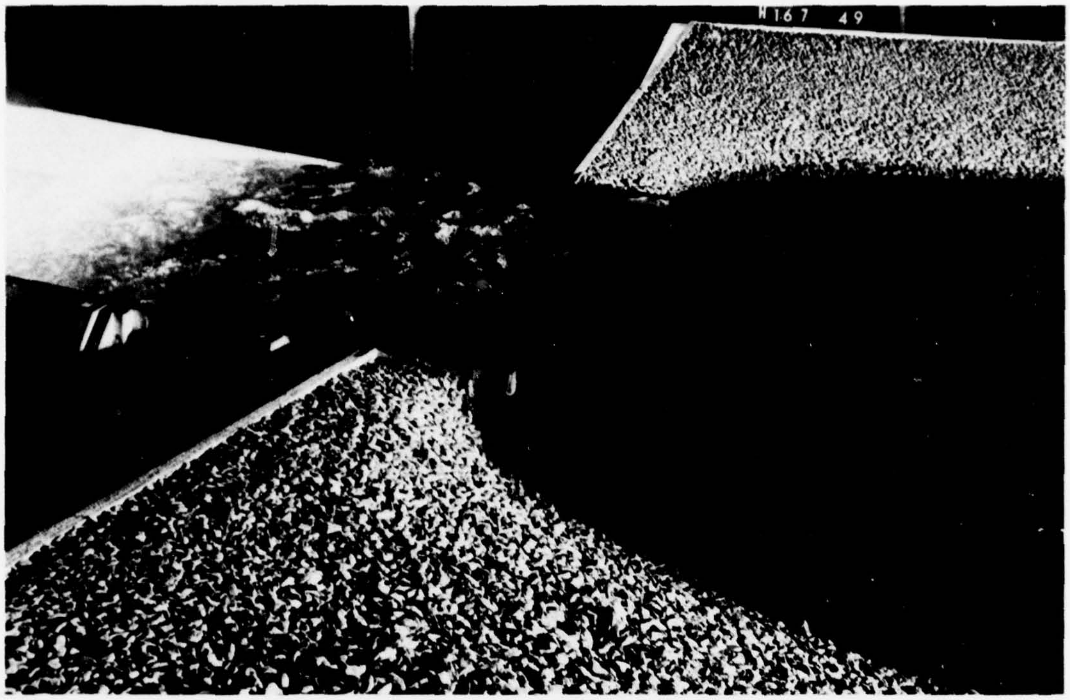


Photo 20. Stilling basin B-3 (original design); design flow 22,700 cfs, tailwater el 129.5

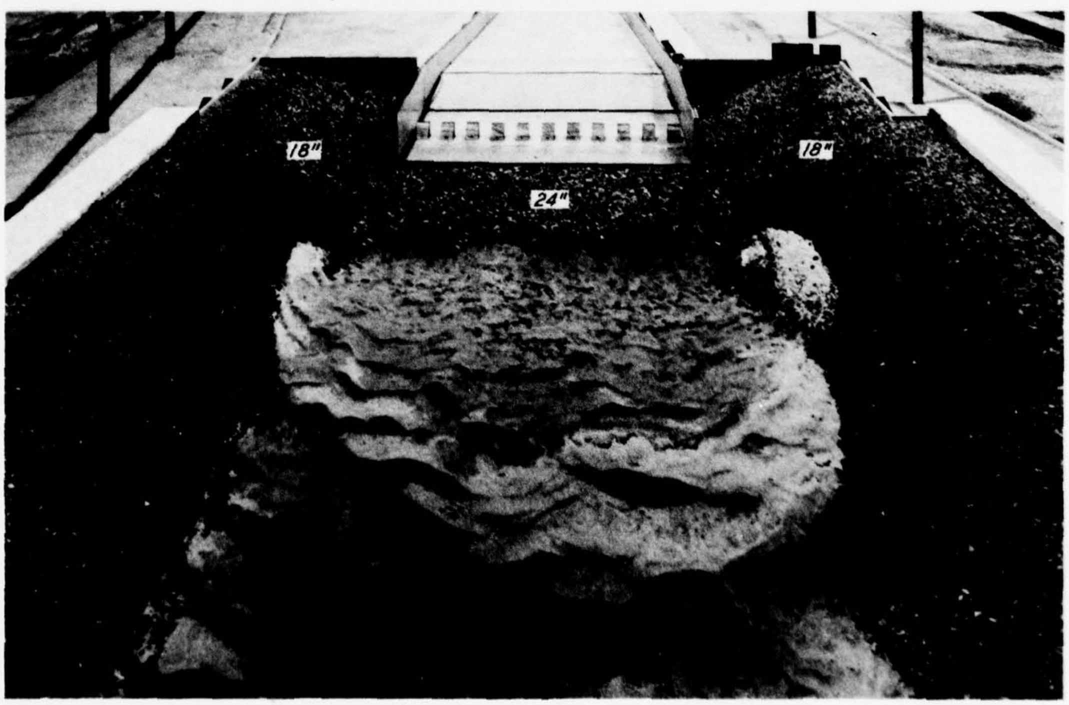


Photo 21. Stilling basin B-1 (type 5) after 1-hr (prototype) operation; type 7 riprap plan, 18-in. riprap on slopes, 24-in. riprap on bottom (el 11.5)

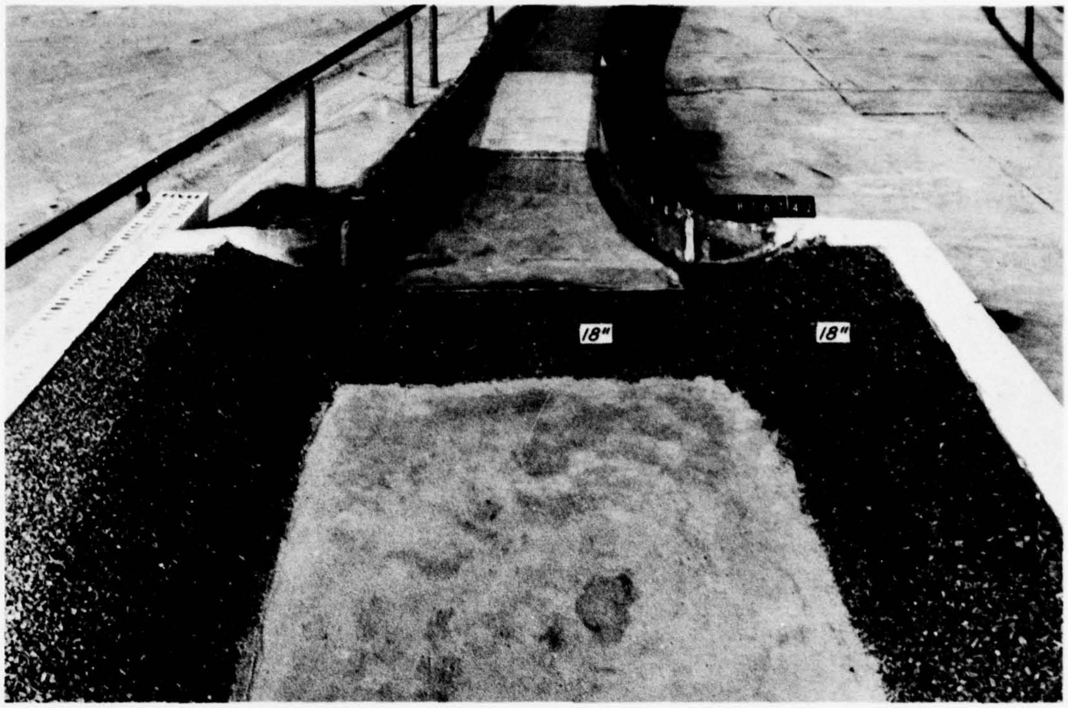
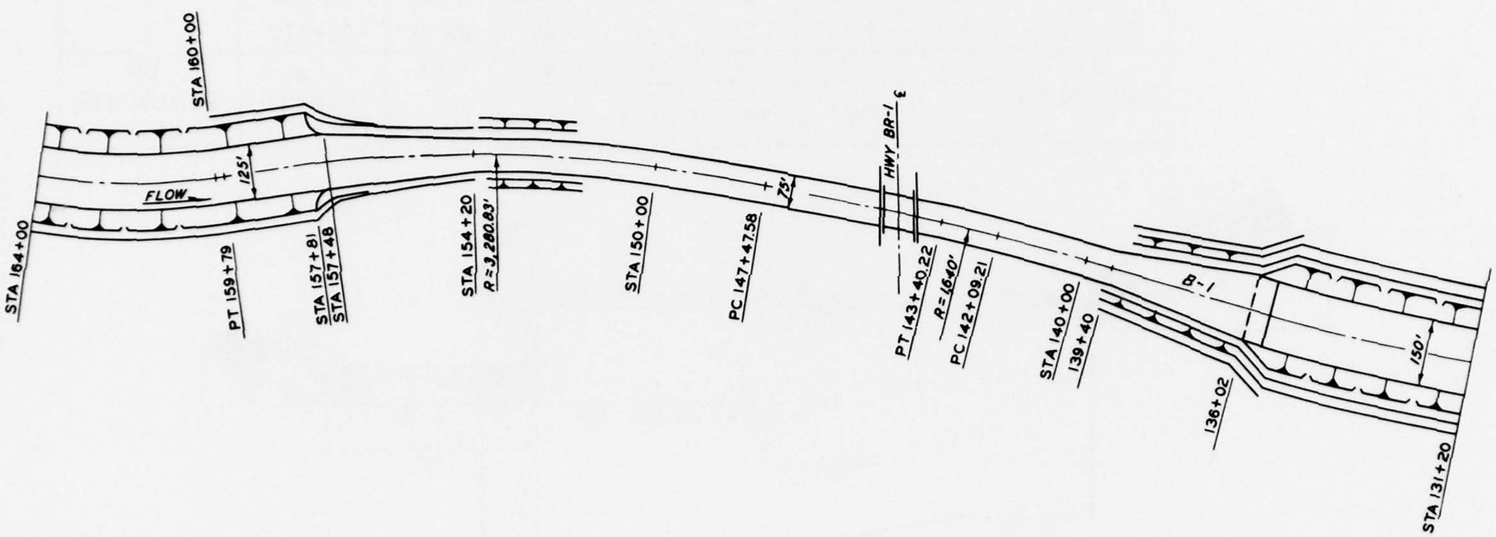
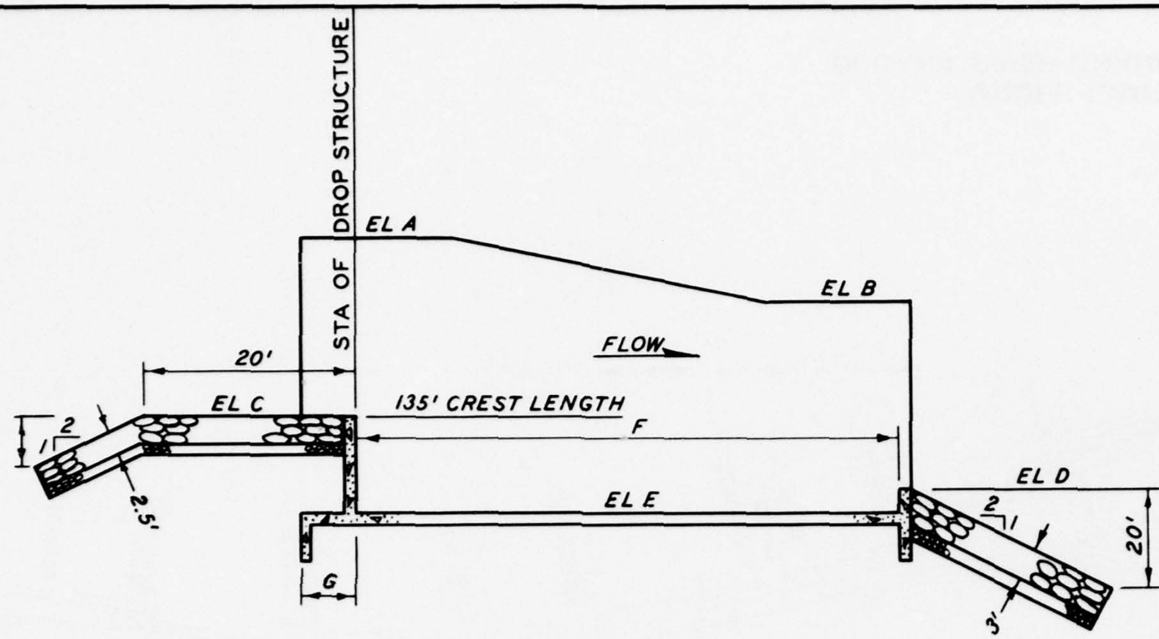


Photo 22. Original riprap plan upstream of the Bucana transition design 3 at sta 157+81

Photo 23. Original riprap plan after 30-min (prototype) operation with design flow 28,900 cfs, Bucana transition design 3

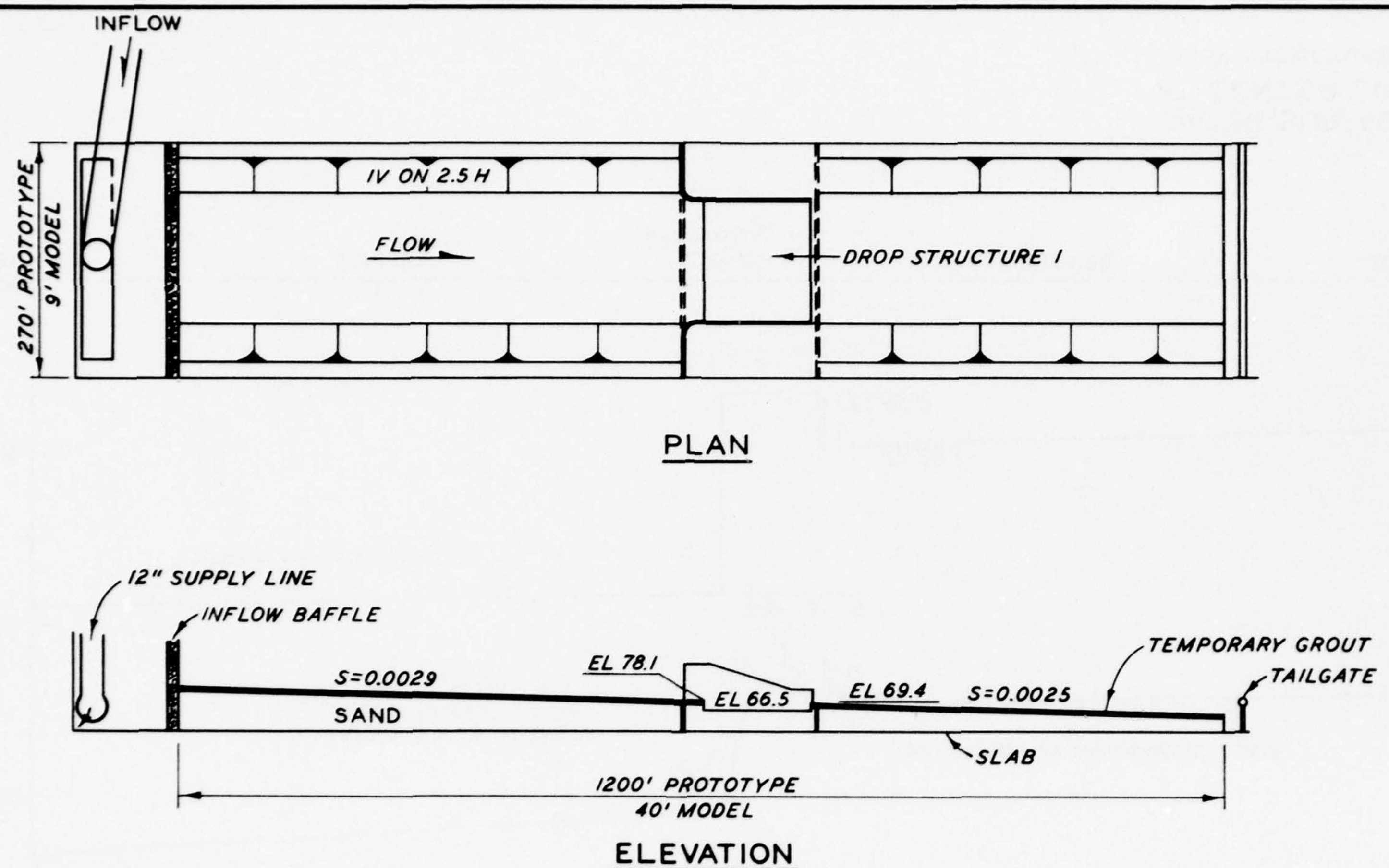


MODEL LIMITS
BUCANA RIVER CHANNELIZATION

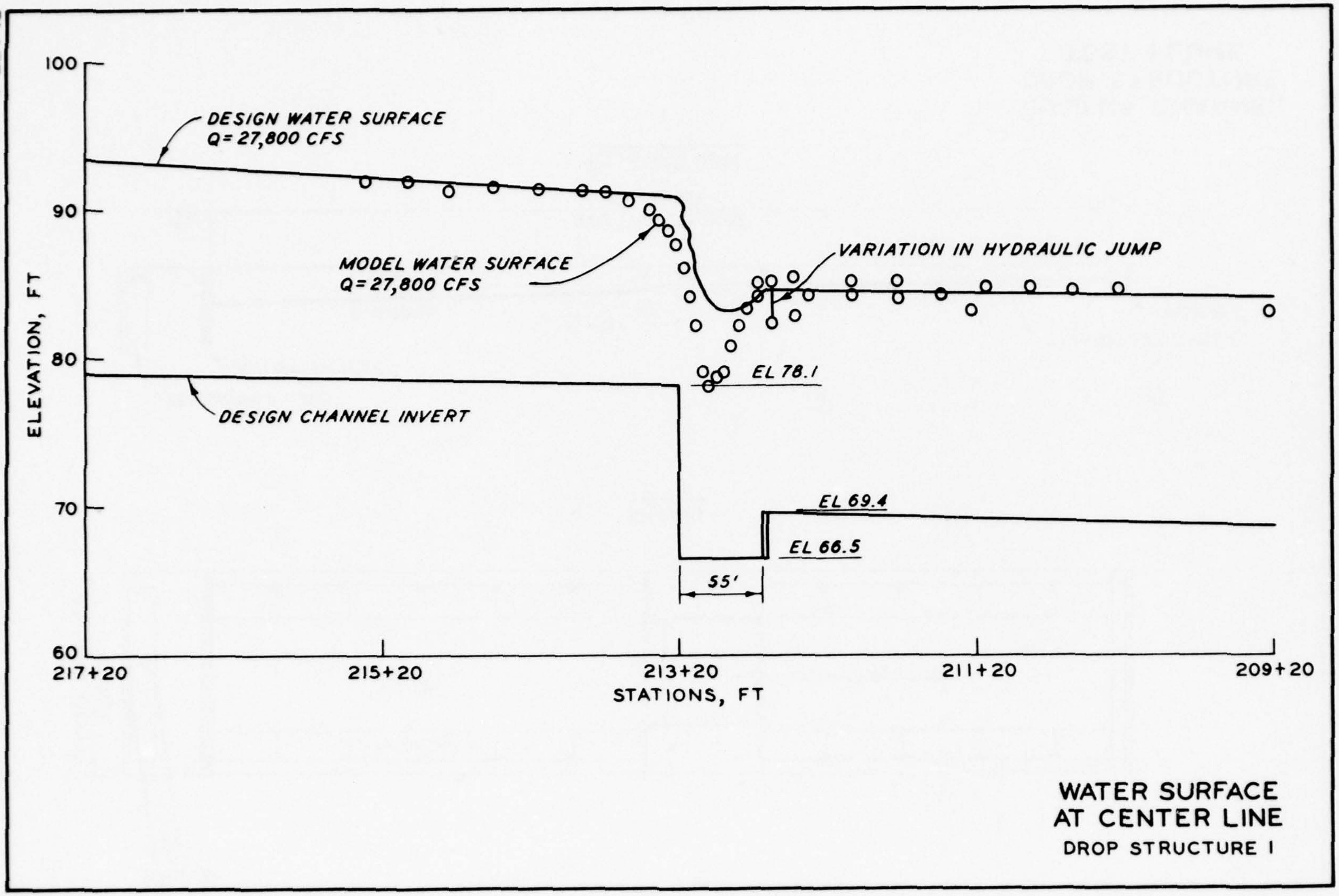


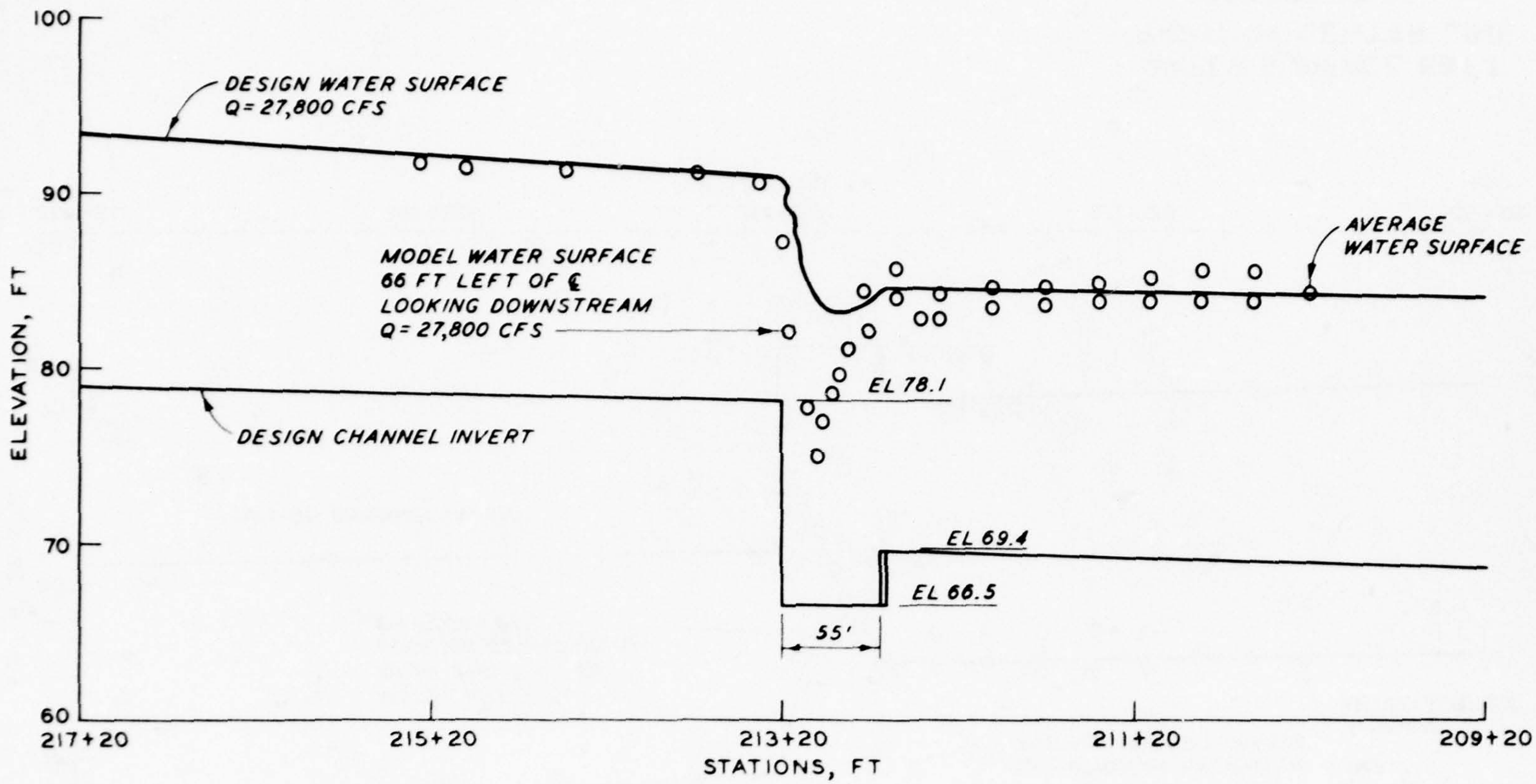
DROP STRUCTURE NO.	STATION FT	Q CFS	ELEVATIONS, FT MSL					DIMENSIONS FT	
			A	B	C	D	E		
1	213 + 20	27,800	95.5	87.7	78.1	69.4	66.5	55.0	5.6
2	233 + 54	24,700	105.6	99.7	89.1	82.5	80.0	50.0	5.2
3	247 + 31	24,700	116.3	109.6	99.8	92.4	89.9	50.0	5.2
4	260 + 43	24,700	126.0	119.7	110.5	102.5	100.0	50.0	5.2

BUCANA DROP STRUCTURE

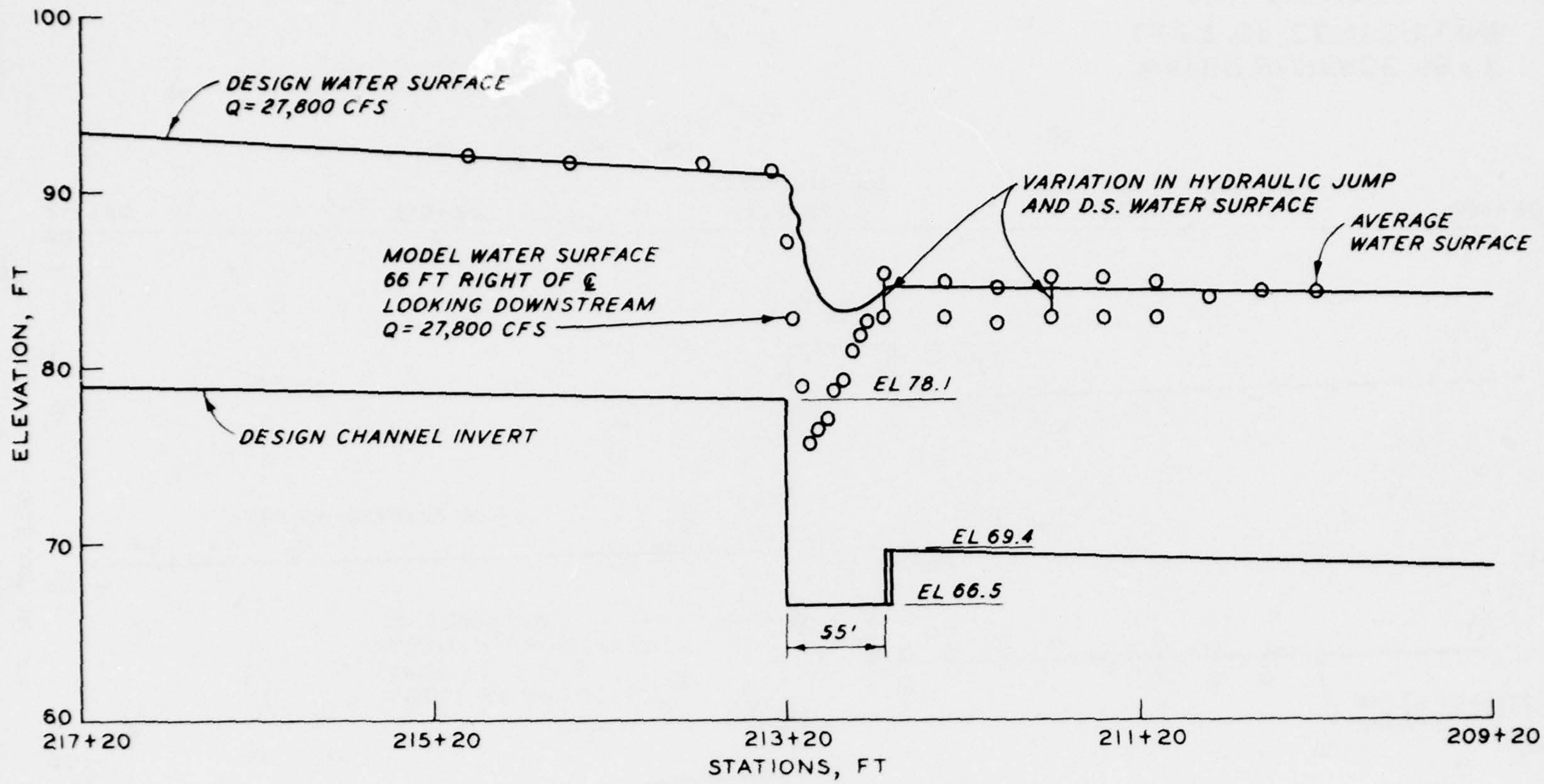


BUCANA CHANNEL
DROP STRUCTURE
TEST FLUME

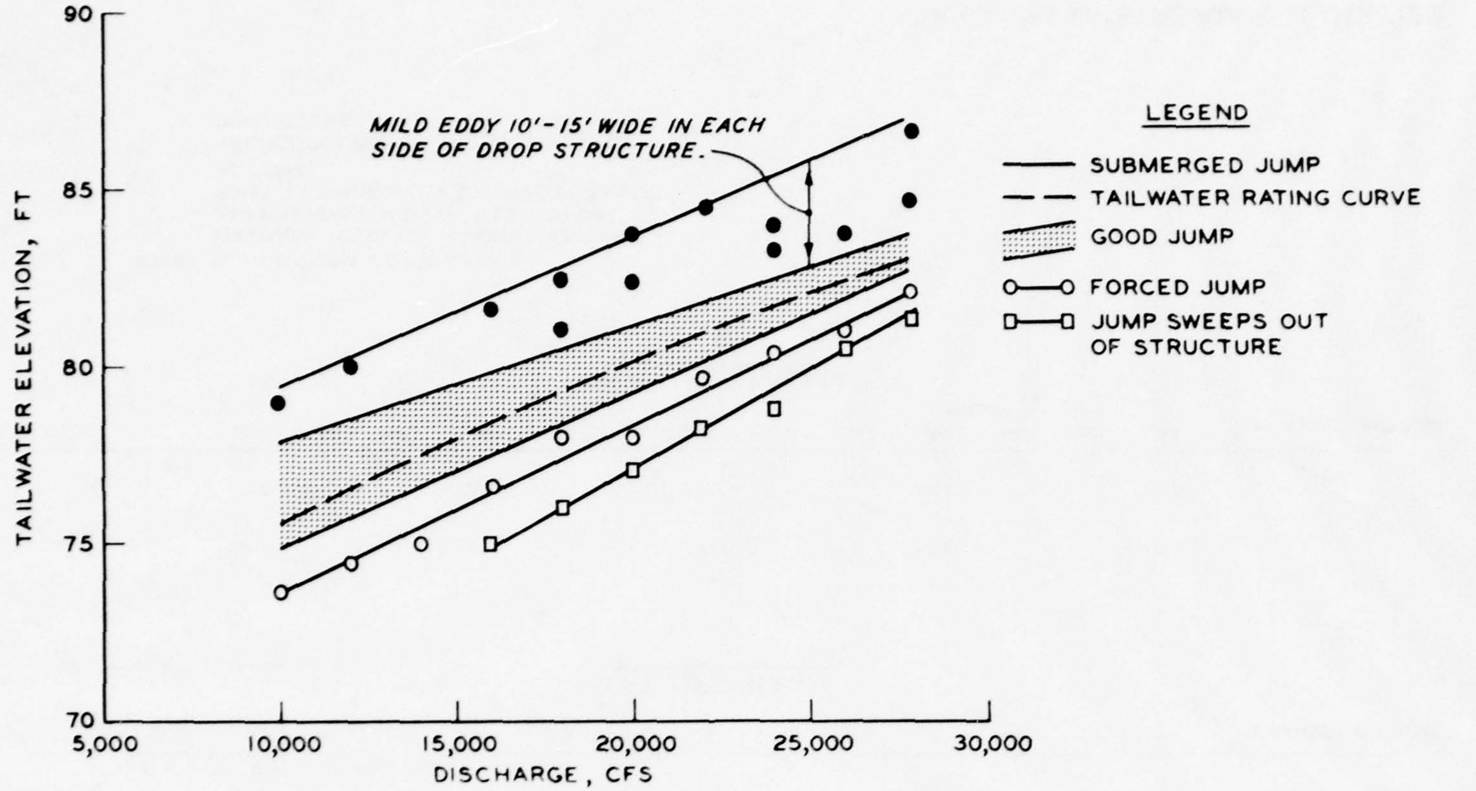

DESIGN WATER SURFACE
Q=27,800 CFS
MODEL WATER SURFACE
Q=27,800 CFS
VARIATION IN HYDRAULIC JUMP
EL 78.1
DESIGN CHANNEL INVERT
EL 69.4
EL 66.5
55'
100
90
80
70
60
ELEVATION, FT
217+20
215+20
213+20
211+20
209+20
STATIONS, FT
WATER SURFACE
AT CENTER LINE
DROP STRUCTURE 1



WATER SURFACE 66 FT
LEFT OF CENTER LINE
DROP STRUCTURE 1



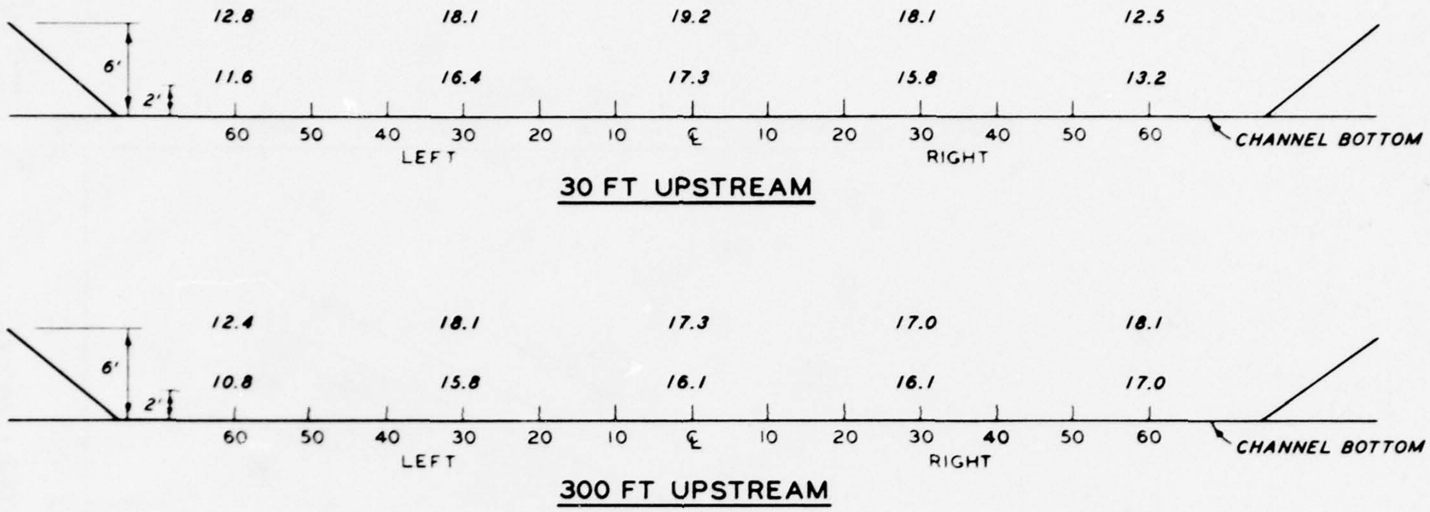
WATER SURFACE 66 FT
RIGHT OF CENTER LINE
DROP STRUCTURE 1



NOTE: EDDIES OCCUR AT TAILWATERS ABOVE THE TAILWATER RATING CURVE.

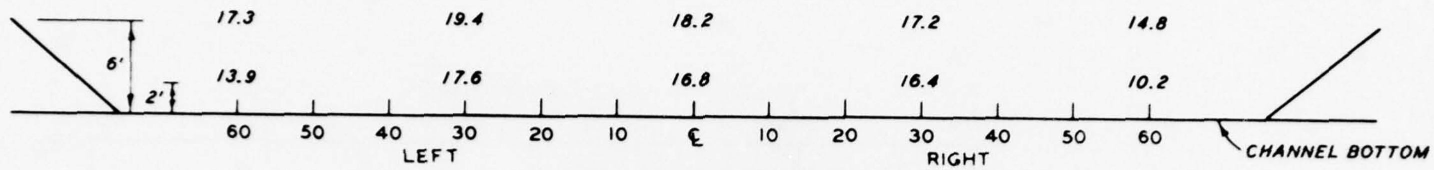
PERFORMANCE CURVES

DROP STRUCTURE 1

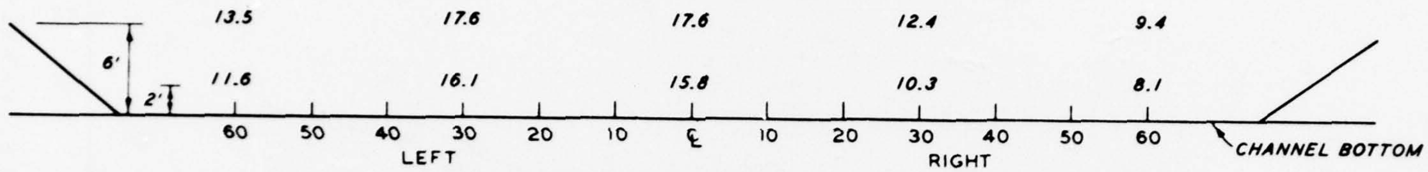


NOTE: DESIGN FLOW 28,700 CFS.
MAXIMUM VELOCITY AGAINST RIPRAP APPROXIMATELY 2 FPS LESS THAN THAT SHOWN FOR 2 FT ABOVE CHANNEL BOTTOM.
VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

MAXIMUM UPSTREAM VELOCITIES
DROP STRUCTURE 1



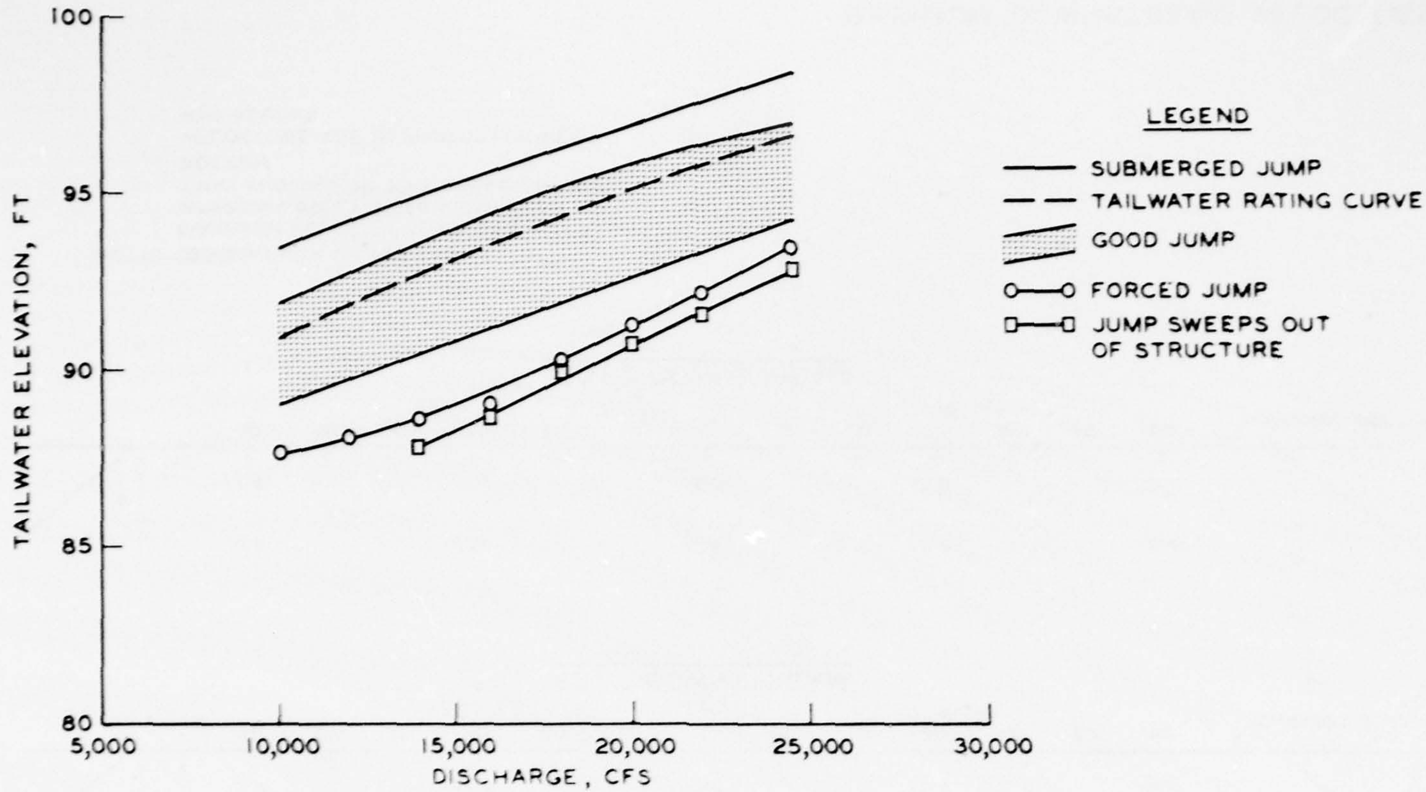
90 FT DOWNSTREAM



300 FT DOWNSTREAM

NOTE: DESIGN FLOW 28,700 CFS.
MAXIMUM VELOCITY AGAINST RIPRAP APPROXIMATELY 2 FPS LESS THAN THAT SHOWN FOR 2 FT ABOVE CHANNEL BOTTOM.
VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

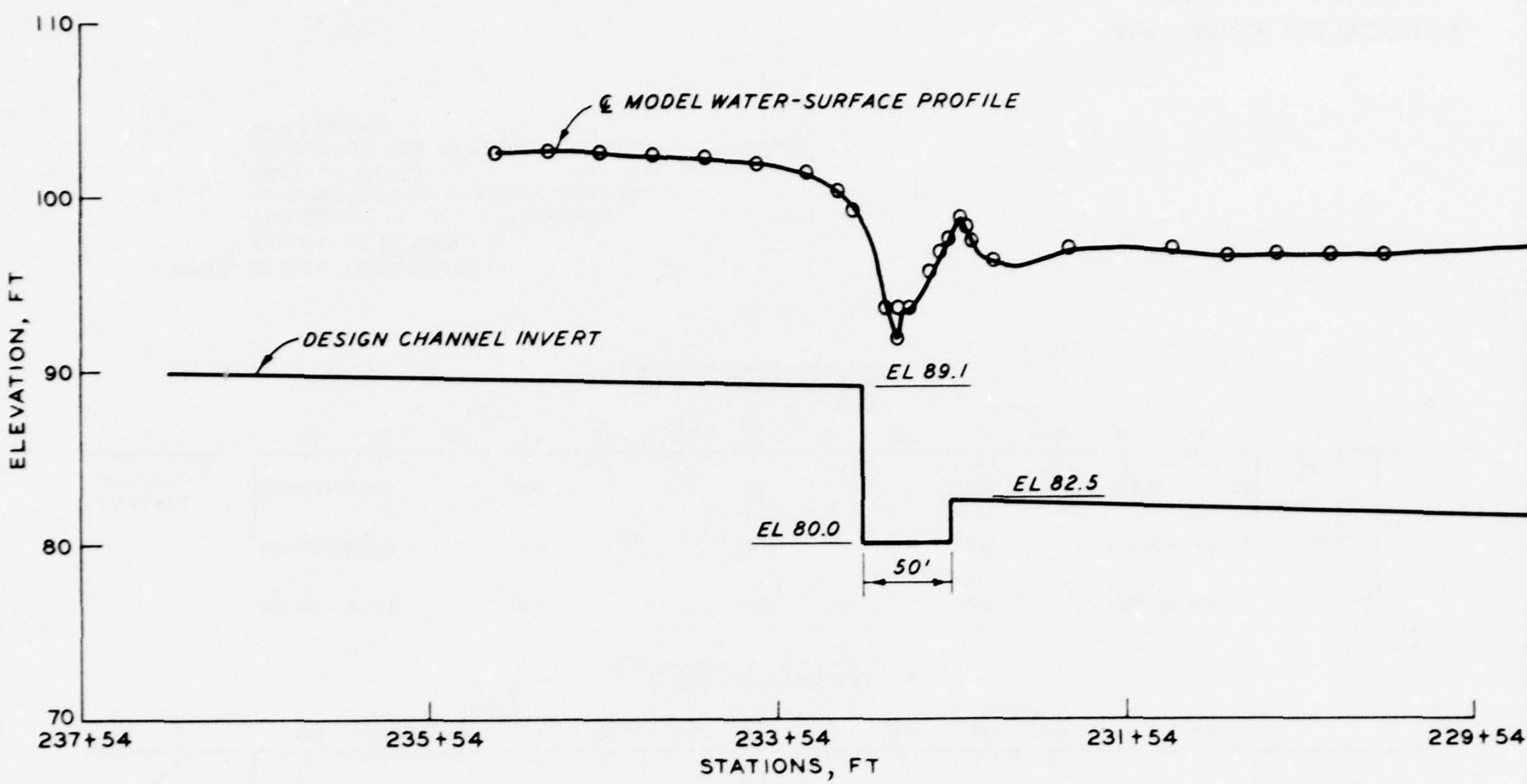
MAXIMUM DOWNSTREAM VELOCITIES
DROP STRUCTURE 1



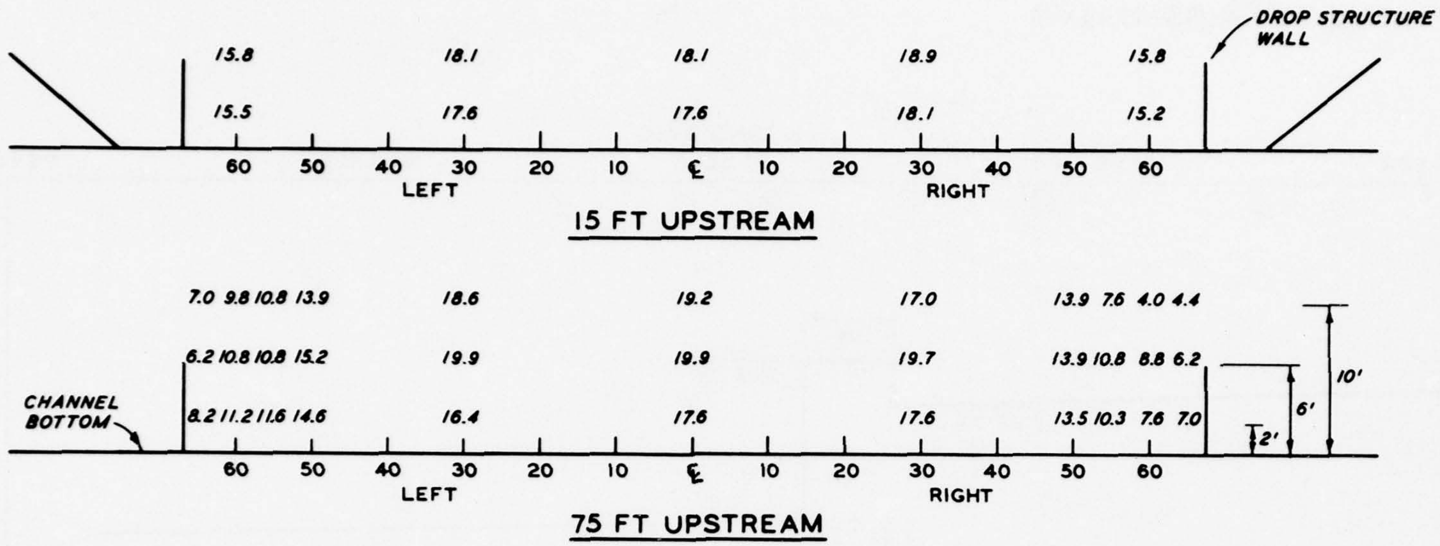
NOTE: EDDIES OCCUR AT TAILWATERS
ABOVE THE TAILWATER RATING CURVE.

PERFORMANCE CURVES

DROP STRUCTURE 2

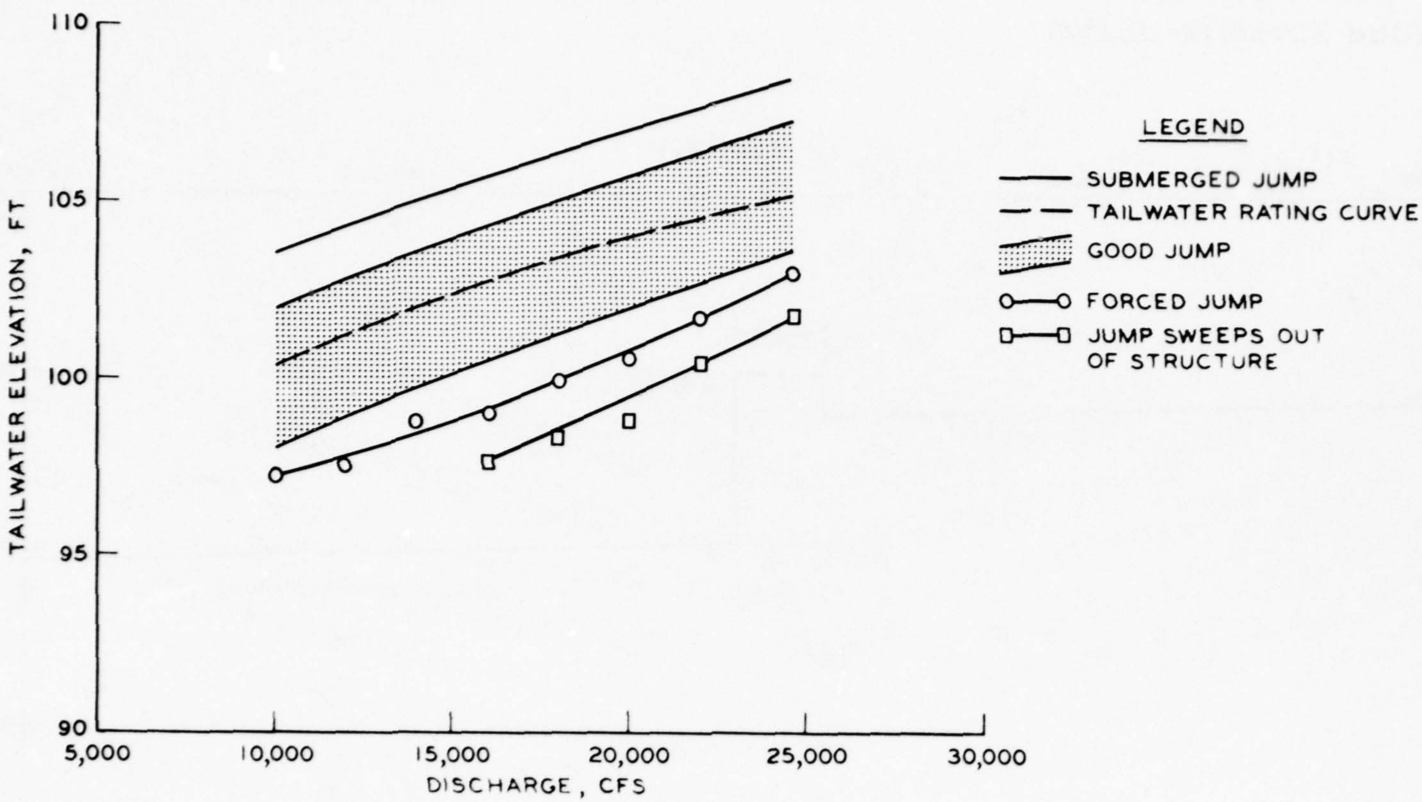


WATER-SURFACE PROFILE
DROP STRUCTURE 2



NOTE: DESIGN FLOW 24,700 CFS
TAILWATER EL 96.5
PROJECTED VELOCITY (MAXIMUM) AGAINST RIPRAP CHANNEL APPROXIMATELY 15 FPS.
VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

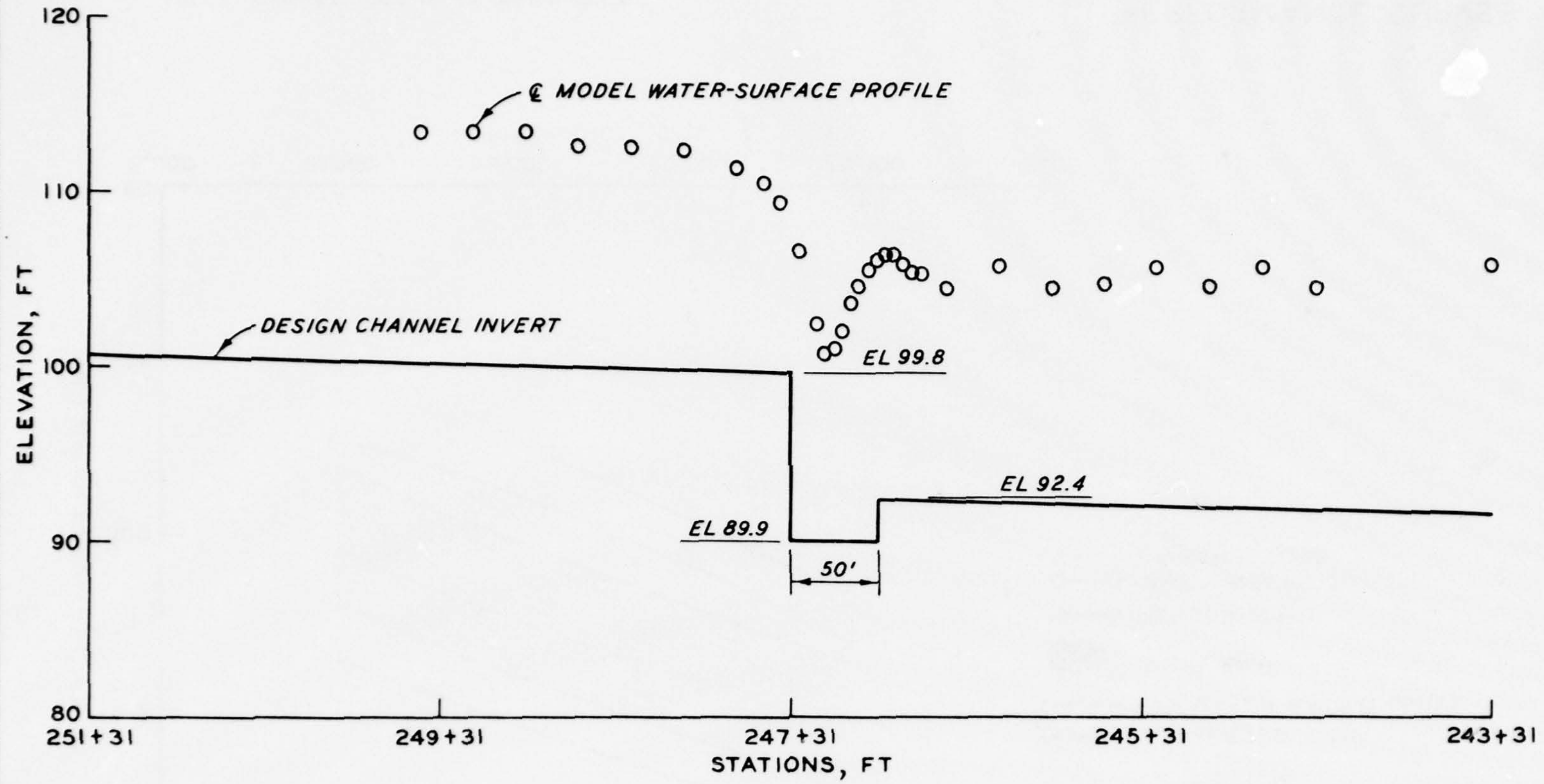
MAXIMUM VELOCITIES
DROP STRUCTURE 2



NOTE: EDDIES OCCUR AT TAILWATERS
ABOVE THE TAILWATER RATING CURVE.

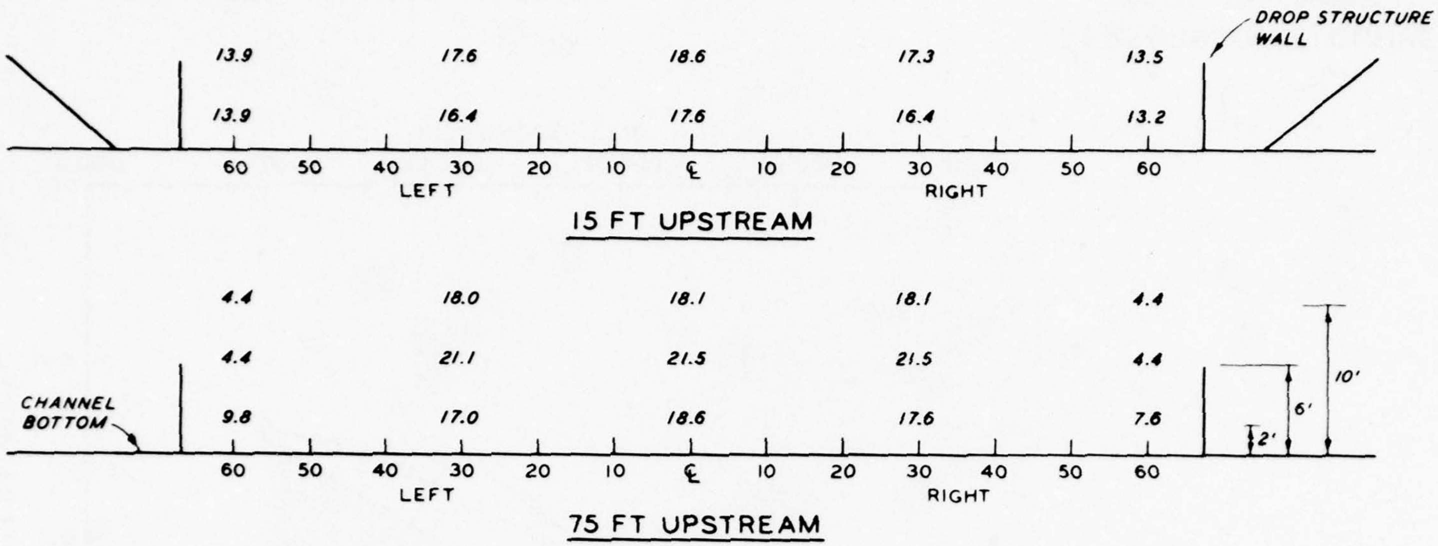
PERFORMANCE CURVES

DROP STRUCTURE 3



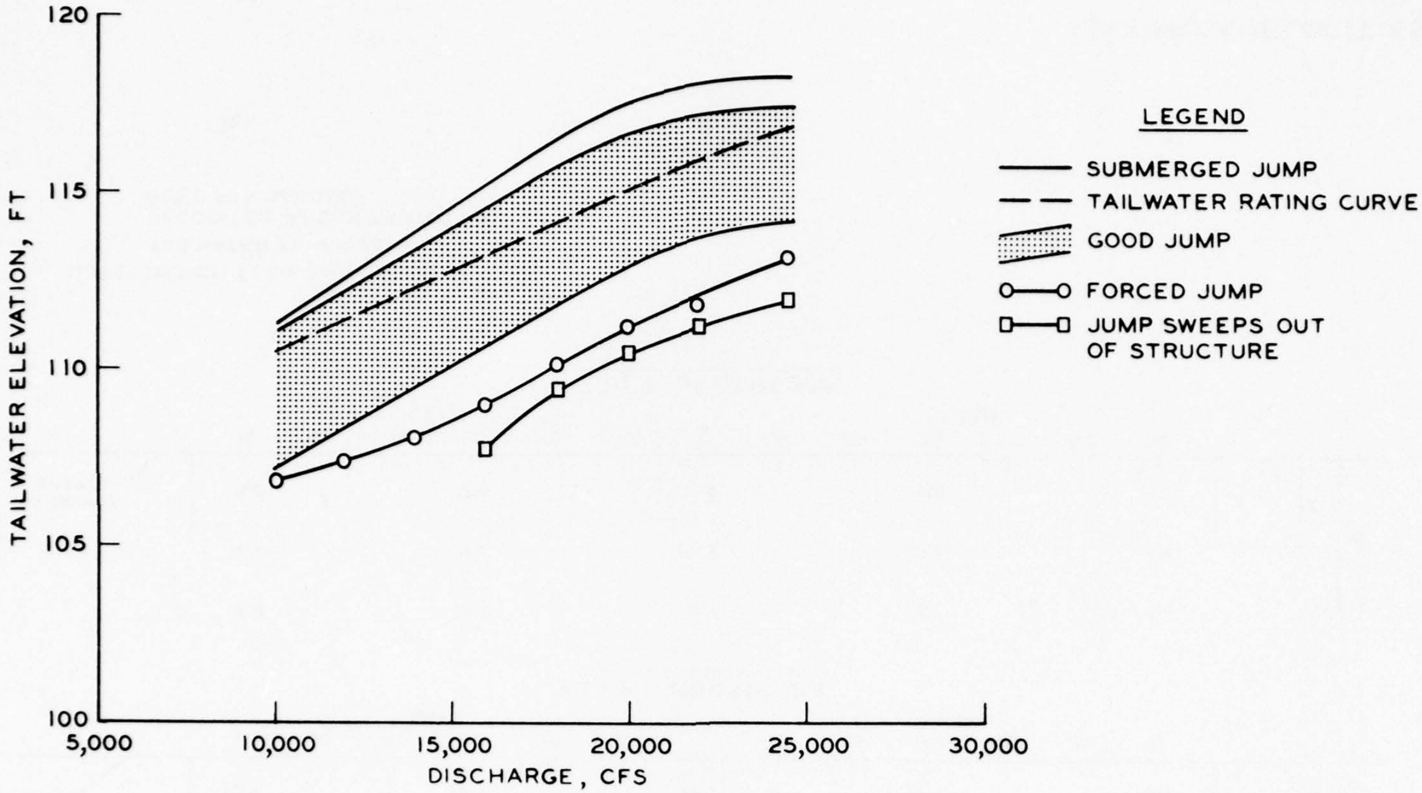
NOTE: DESIGN FLOW 24,700 CFS.

WATER-SURFACE PROFILE
DROP STRUCTURE 3



NOTE: DESIGN FLOW 24,700 CFS
TAILWATER EL 105.20
VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

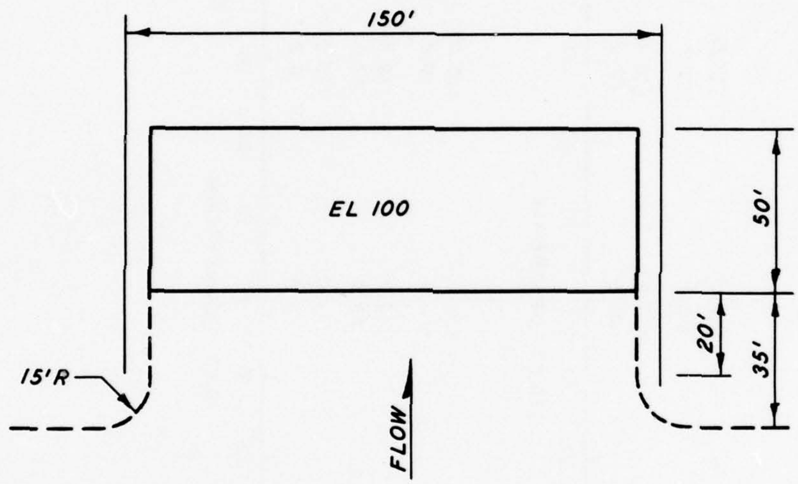
MAXIMUM VELOCITIES
DROP STRUCTURE 3



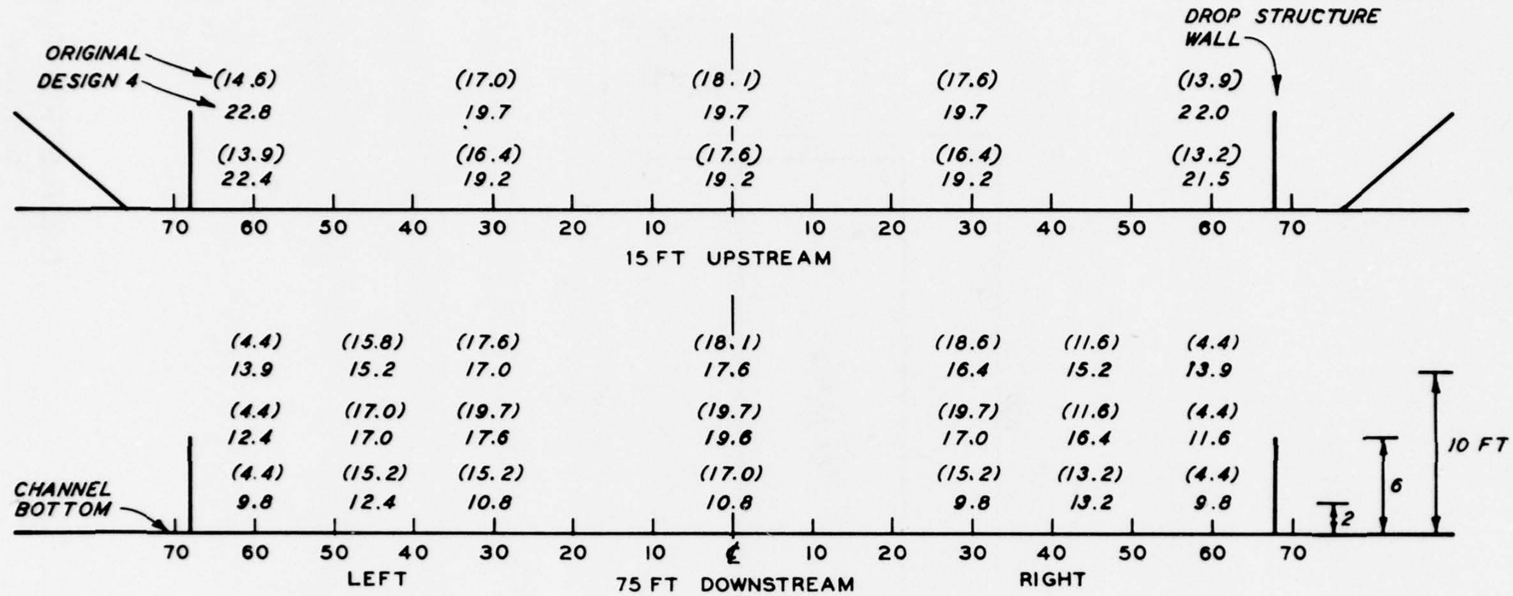
NOTE: EDDIES OCCUR AT TAILWATERS ABOVE THE TAILWATER RATING CURVE.

PERFORMANCE CURVES

DROP STRUCTURE 4
ORIGINAL DESIGN

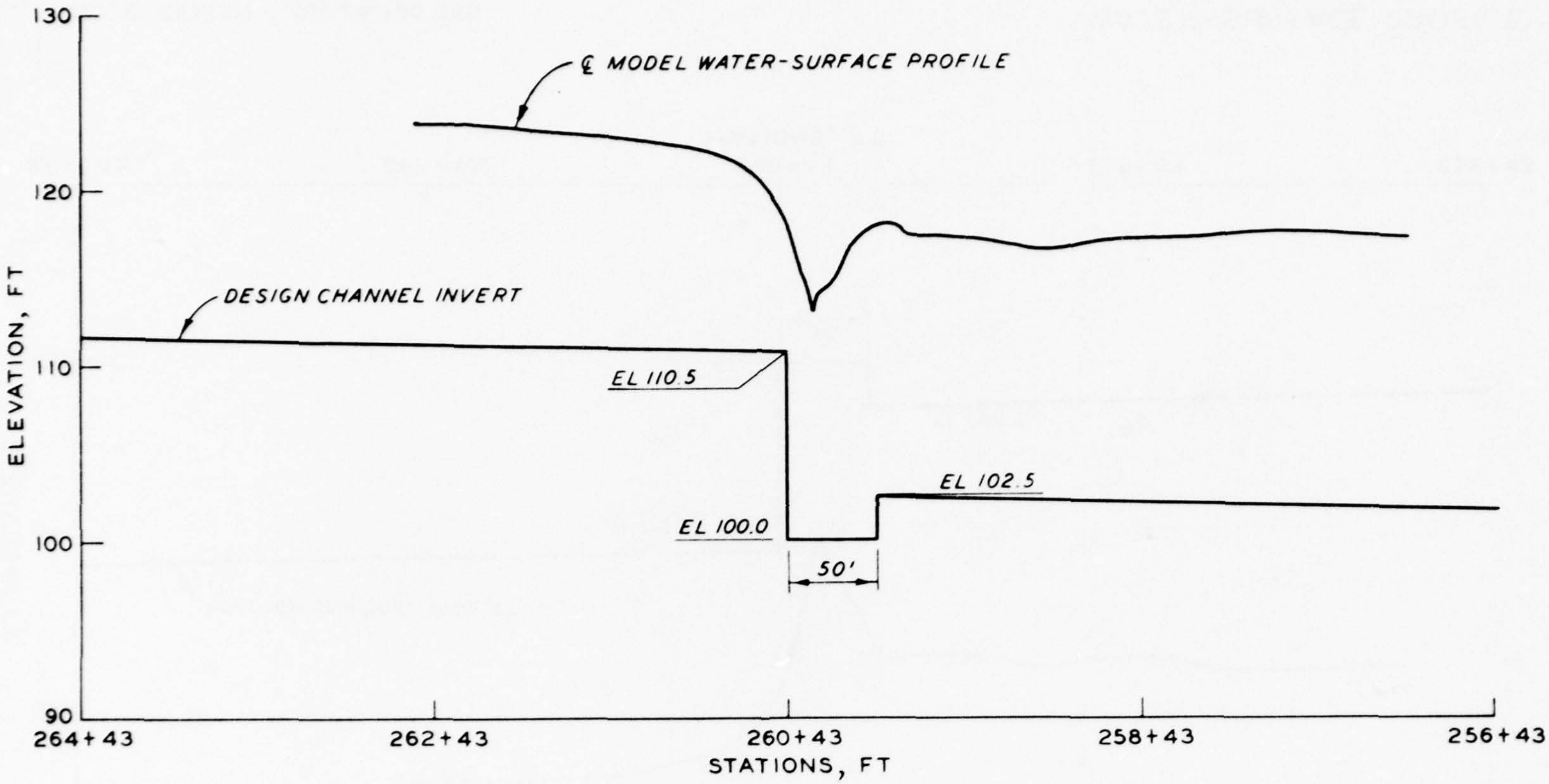


DROP STRUCTURE 4
DESIGN 4



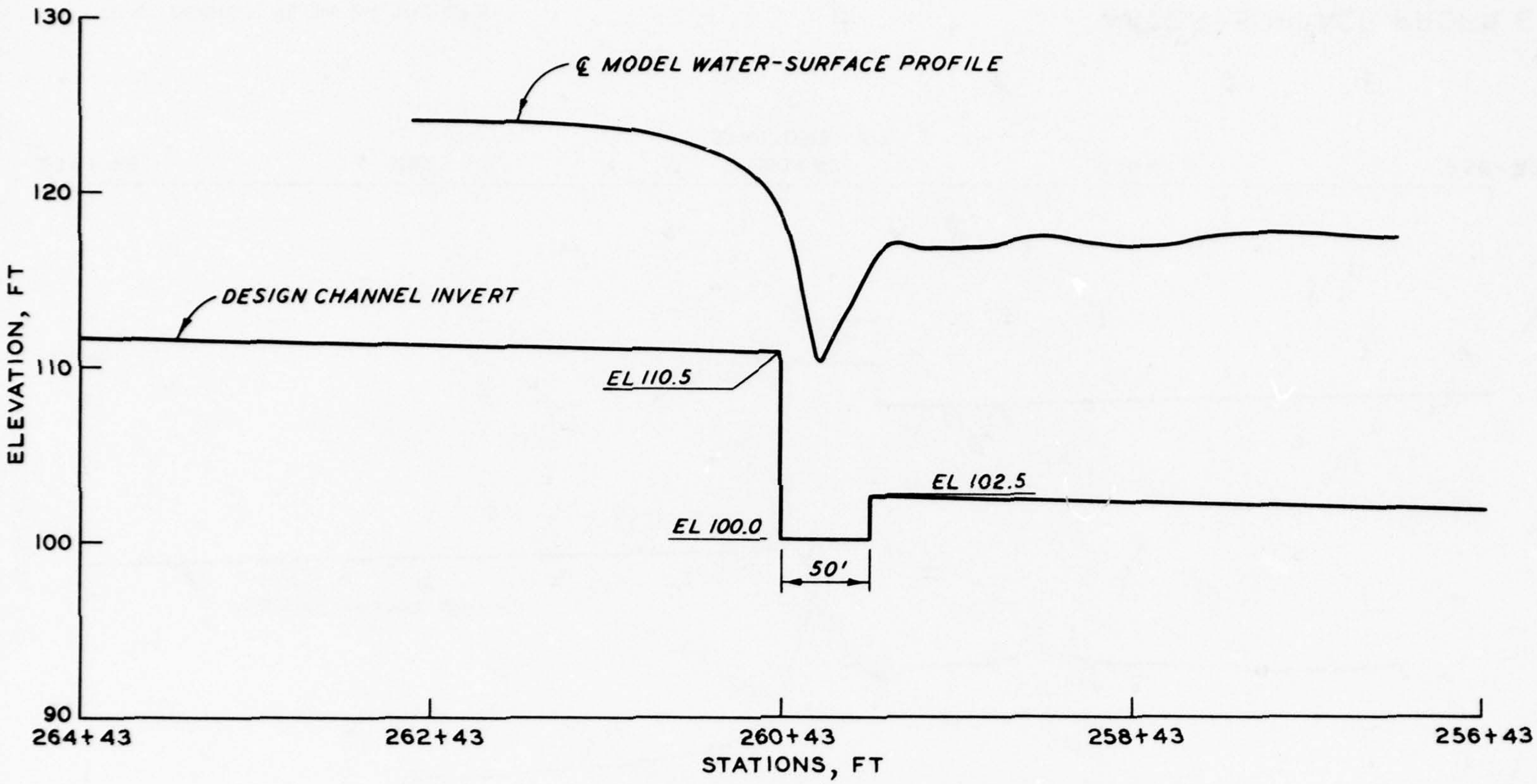
NOTE: DESIGN FLOW 24,700 CFS
TAILWATER EL 116.87
VELOCITIES ARE IN PROTOTYPE FEET PER SECOND
ORIGINAL VELOCITIES ARE SHOWN IN PARENTHESES

MAXIMUM VELOCITIES
DROP STRUCTURE 4
DESIGN 4 VERSUS ORIGINAL DESIGN



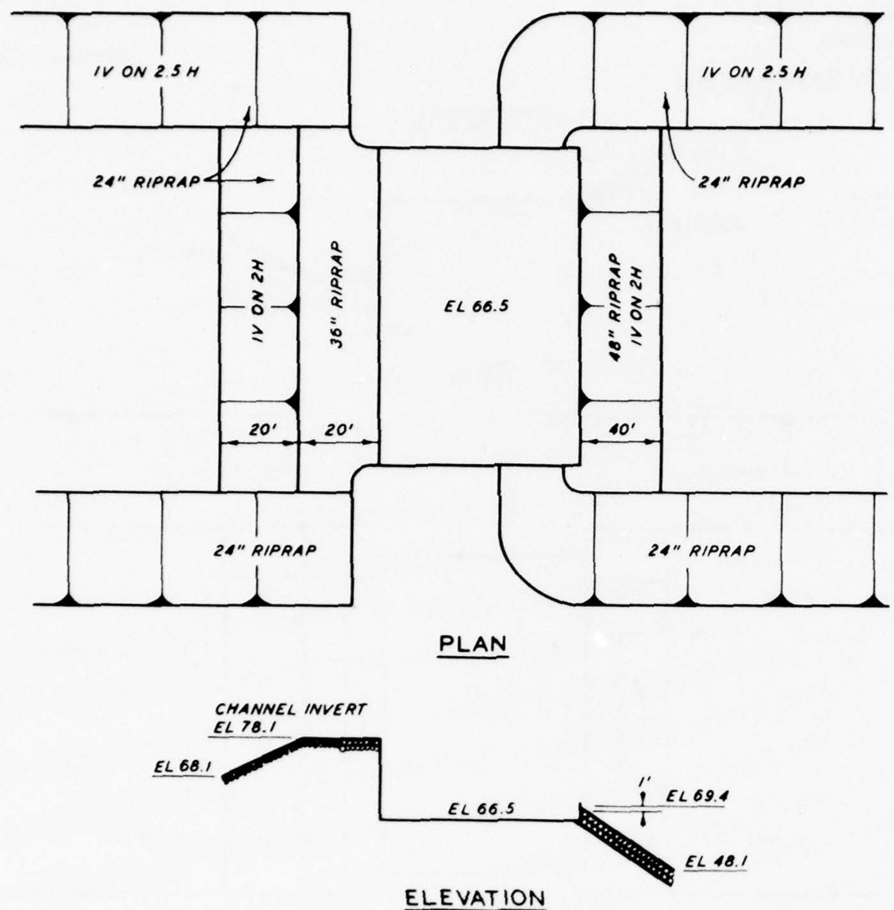
NOTE: DESIGN FLOW 24,700 CFS
HEADWATER EL 122.25
TAILWATER EL 116.87

WATER-SURFACE PROFILE
DROP STRUCTURE 4
ORIGINAL DESIGN



NOTE: DESIGN FLOW 24,700 CFS
HEADWATER EL 122.25
TAILWATER EL 116.87

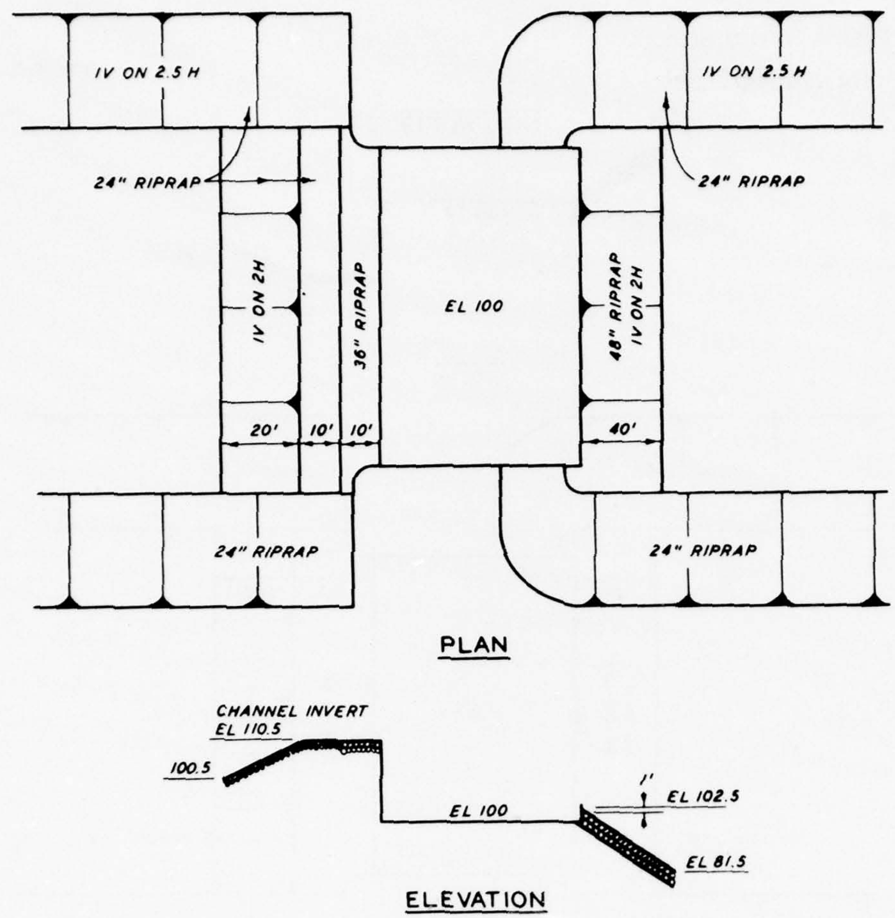
WATER-SURFACE PROFILE
DROP STRUCTURE 4
DESIGN 4



NOTE: NOT TO SCALE

RECOMMENDED RIPRAP PLAN 10

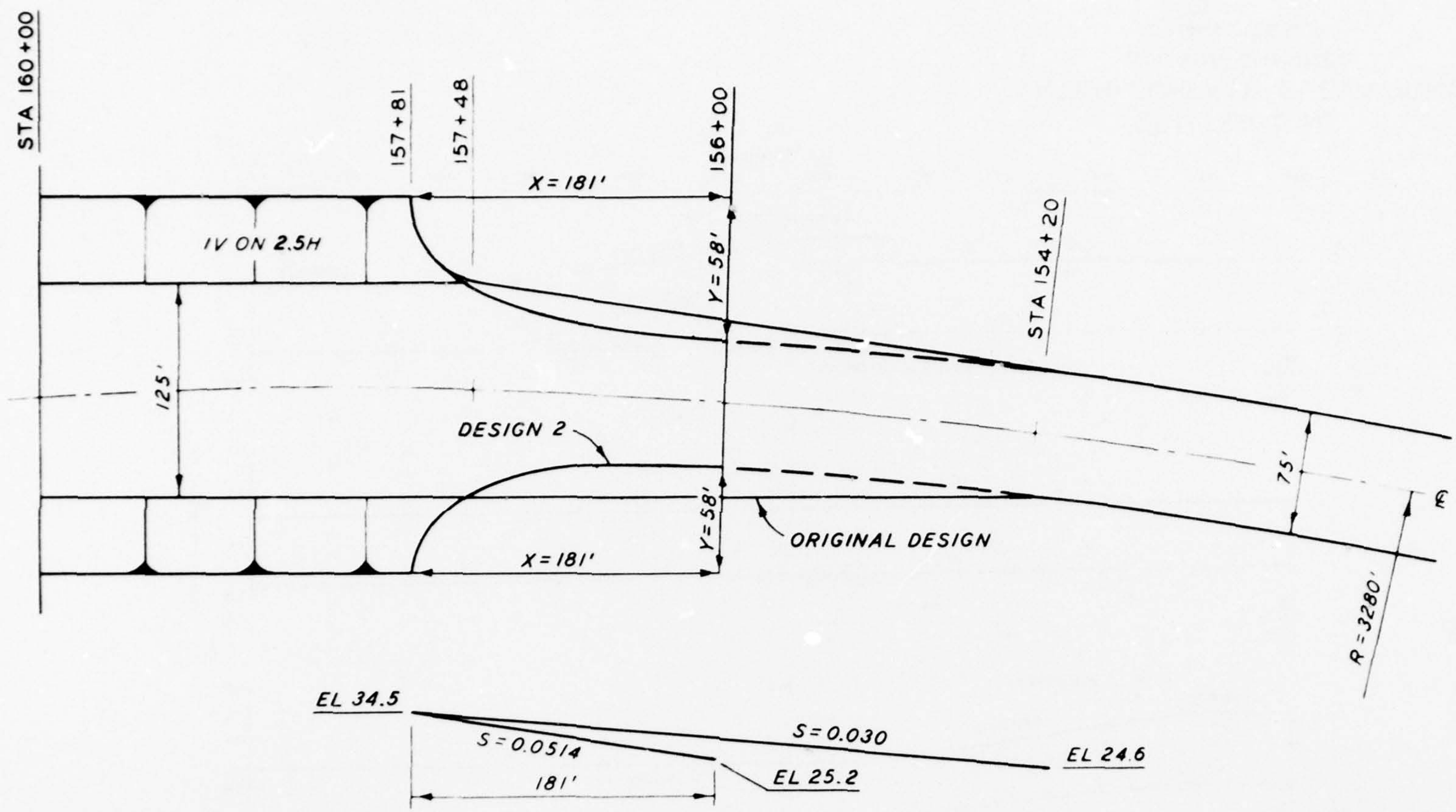
ORIGINAL BASIN FOR DROP STRUCTURE 1



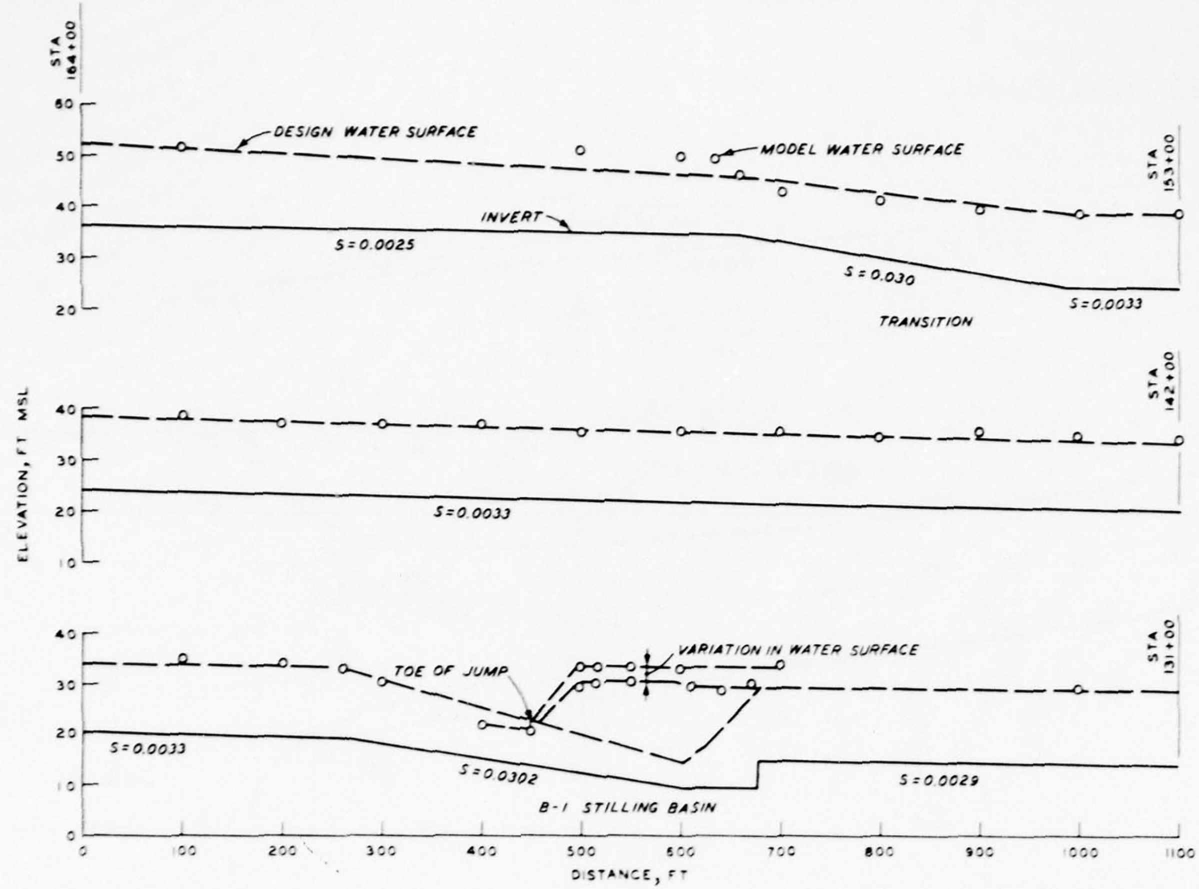
NOTE: NOT TO SCALE

RECOMMENDED RIPRAP PLAN 8

ORIGINAL BASIN FOR
DROP STRUCTURES 2, 3, AND 4



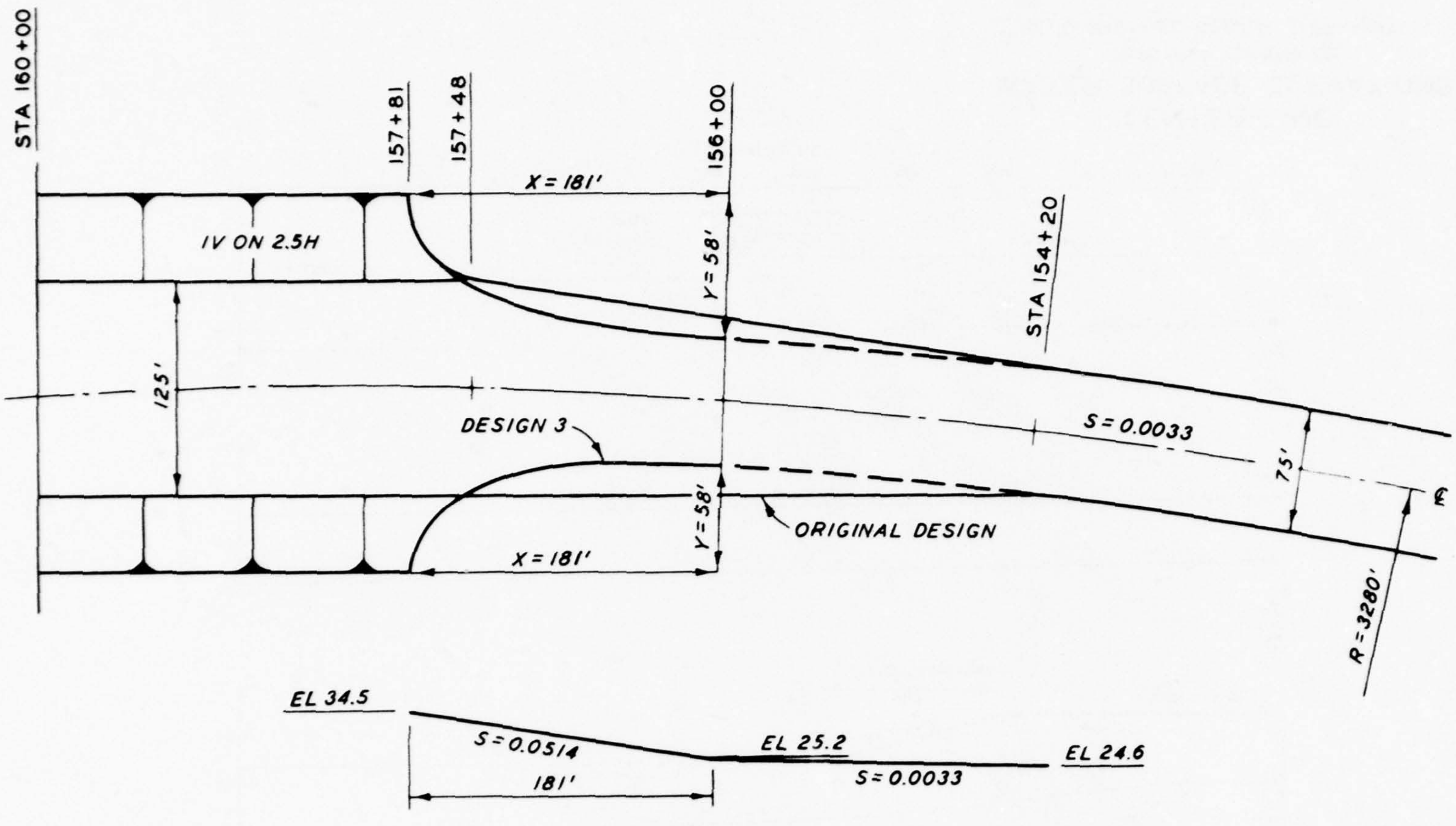
TRANSITION DESIGN 2
BUCANA CHANNEL



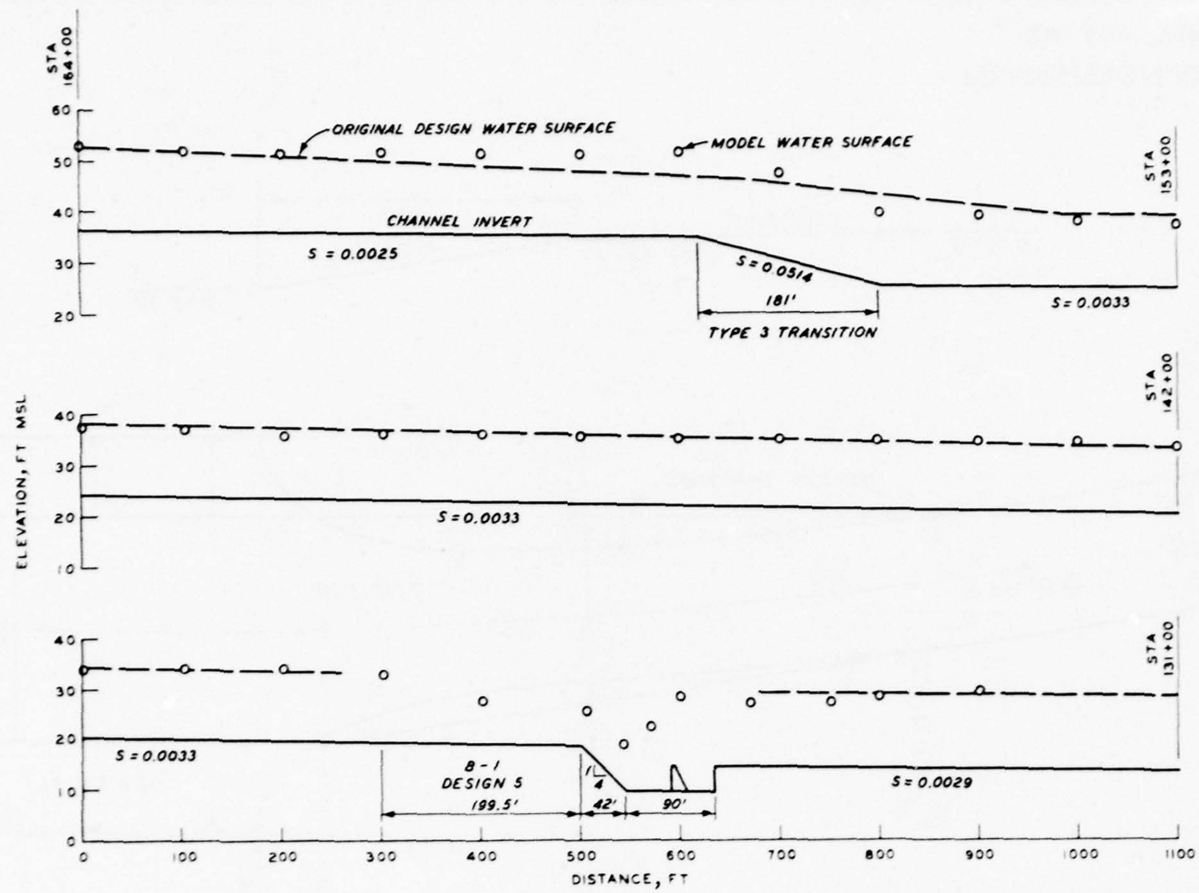
CENTER-LINE WATER-SURFACE ELEVATIONS

BUCANA CHANNEL

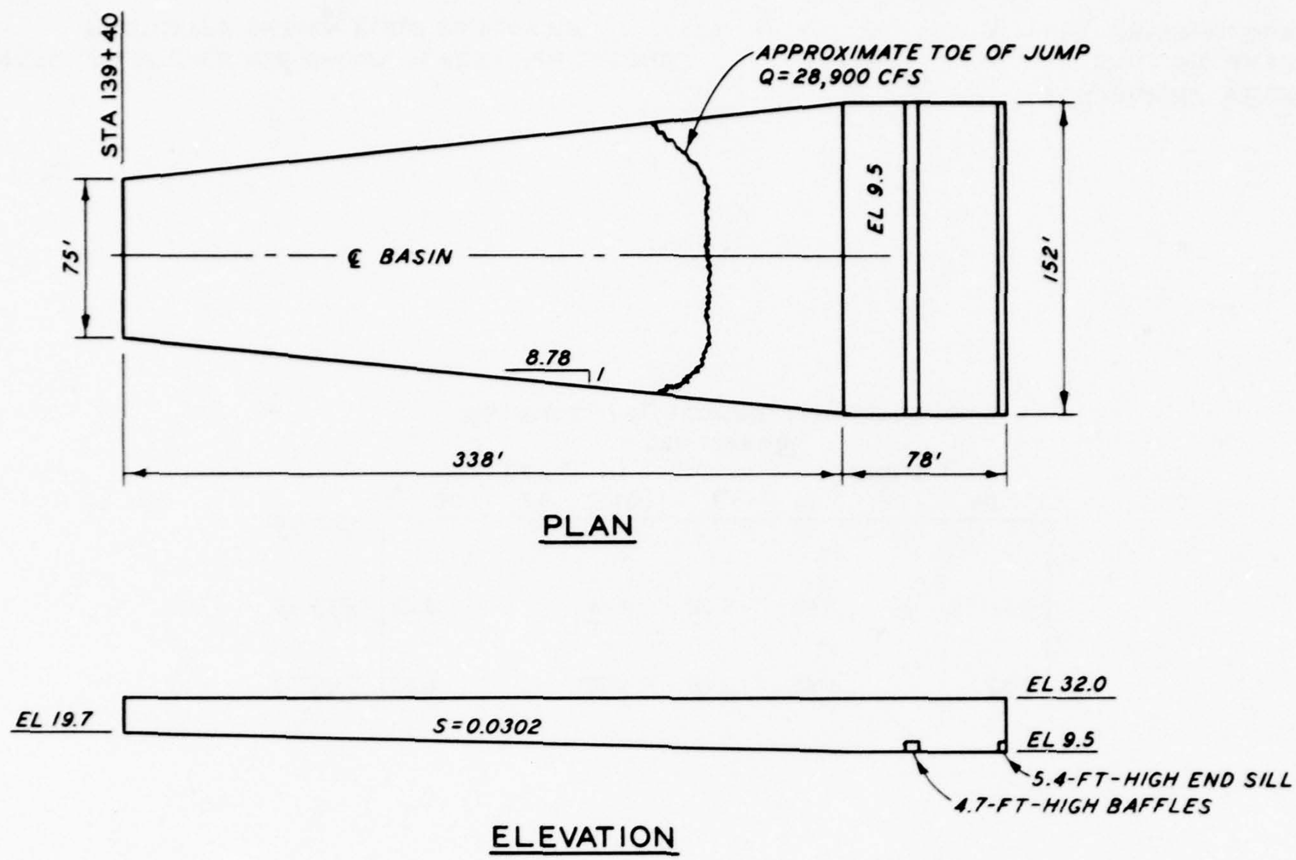
ORIGINAL DESIGN



TRANSITION DESIGN 3
BUCANA CHANNEL

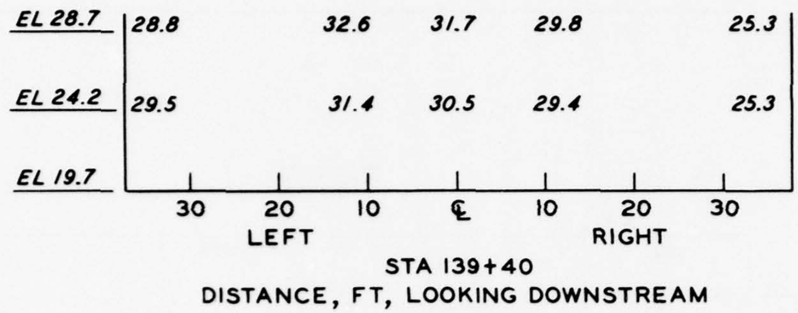


CENTER-LINE
WATER-SURFACE ELEVATIONS
BUCANA CHANNEL
RECOMMENDED DESIGN 3 TRANSITION



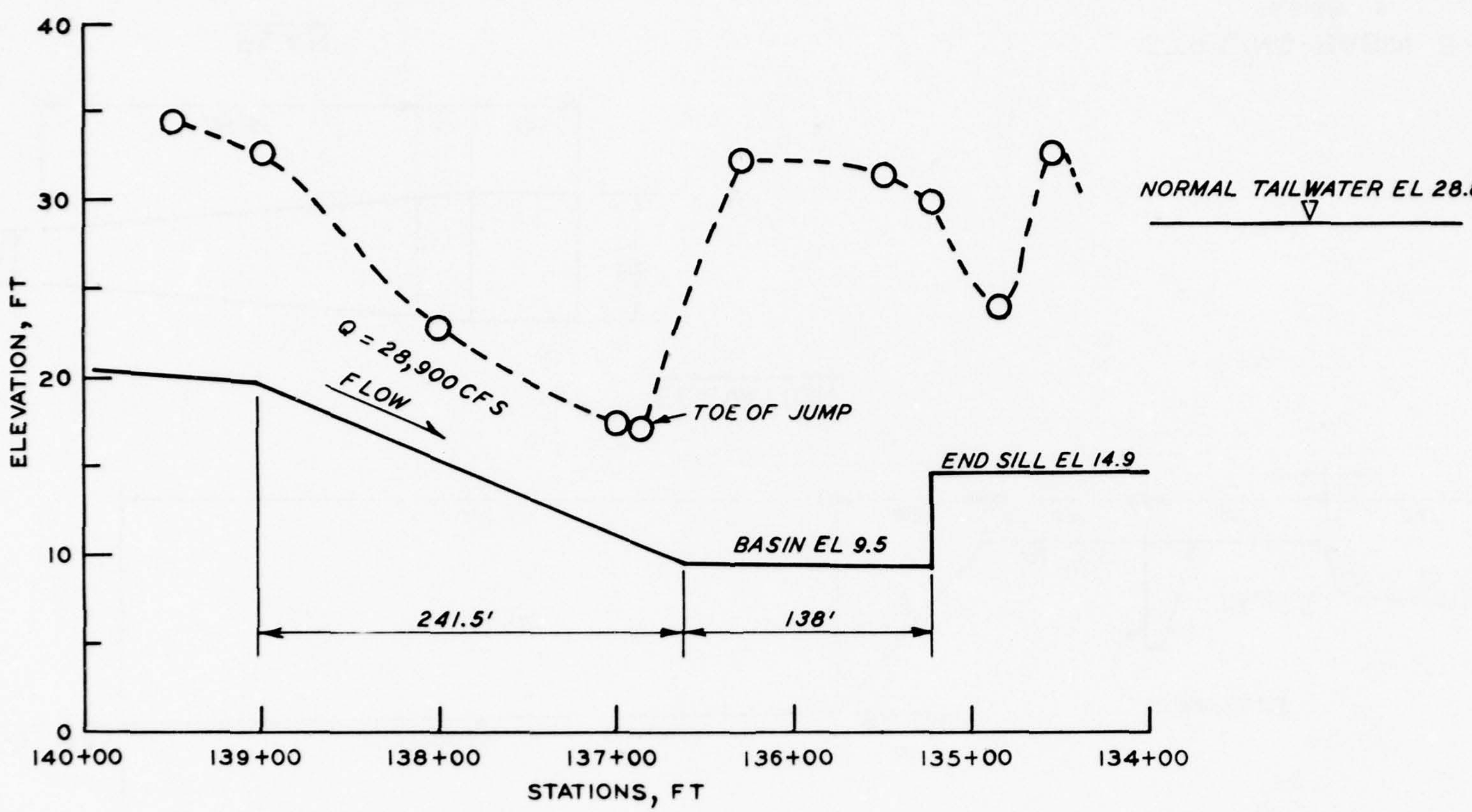
NOTE: BAFFLE BLOCKS 6 FT BY 6 FT

STILLING BASIN B-1
ORIGINAL DESIGN

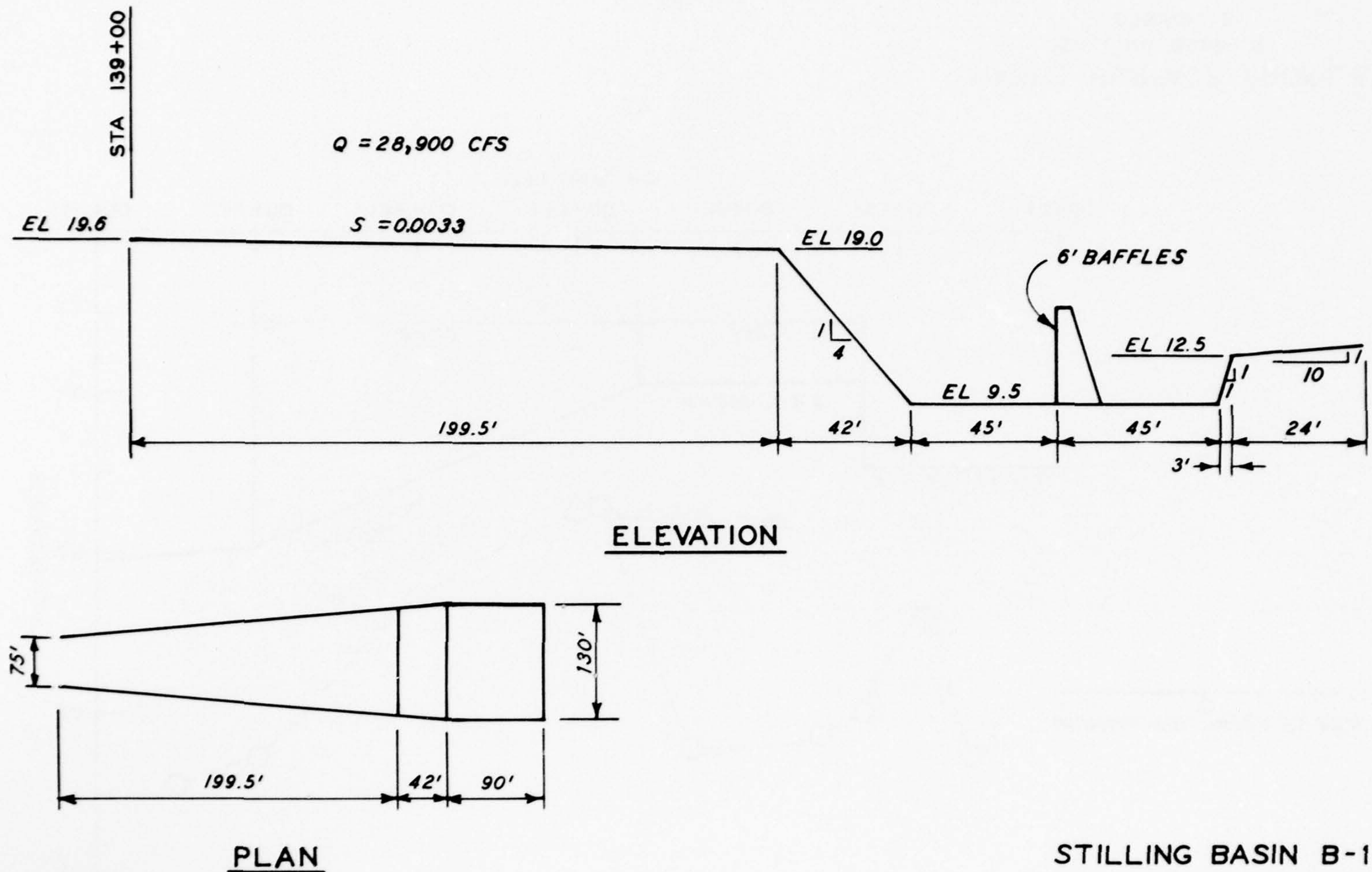


NOTE: VELOCITIES ARE SHOWN IN FEET PER SECOND.
PROTOTYPE DESIGN FLOW 28,900 CFS.

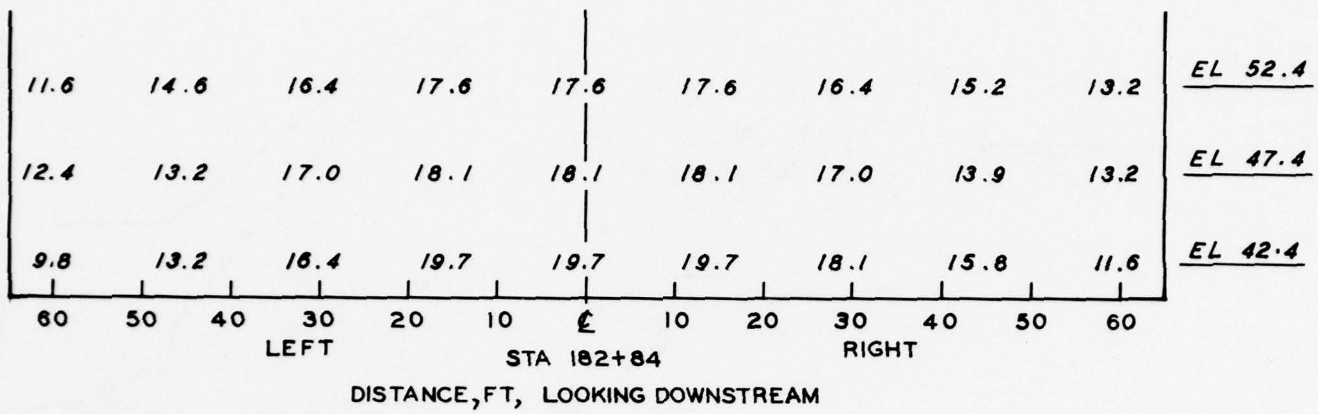
MAXIMUM VELOCITIES
STILLING BASIN B-1
ORIGINAL DESIGN



WATER-SURFACE PROFILE
STILLING BASIN B-1
DESIGN 2



STILLING BASIN B-1
DESIGN 5



NOTE: VELOCITIES ARE IN PROTOTYPE
FEET PER SECOND.
DESIGN FLOW 28,400 CFS.

MAXIMUM VELOCITIES
STILLING BASIN B-2
ORIGINAL DESIGN

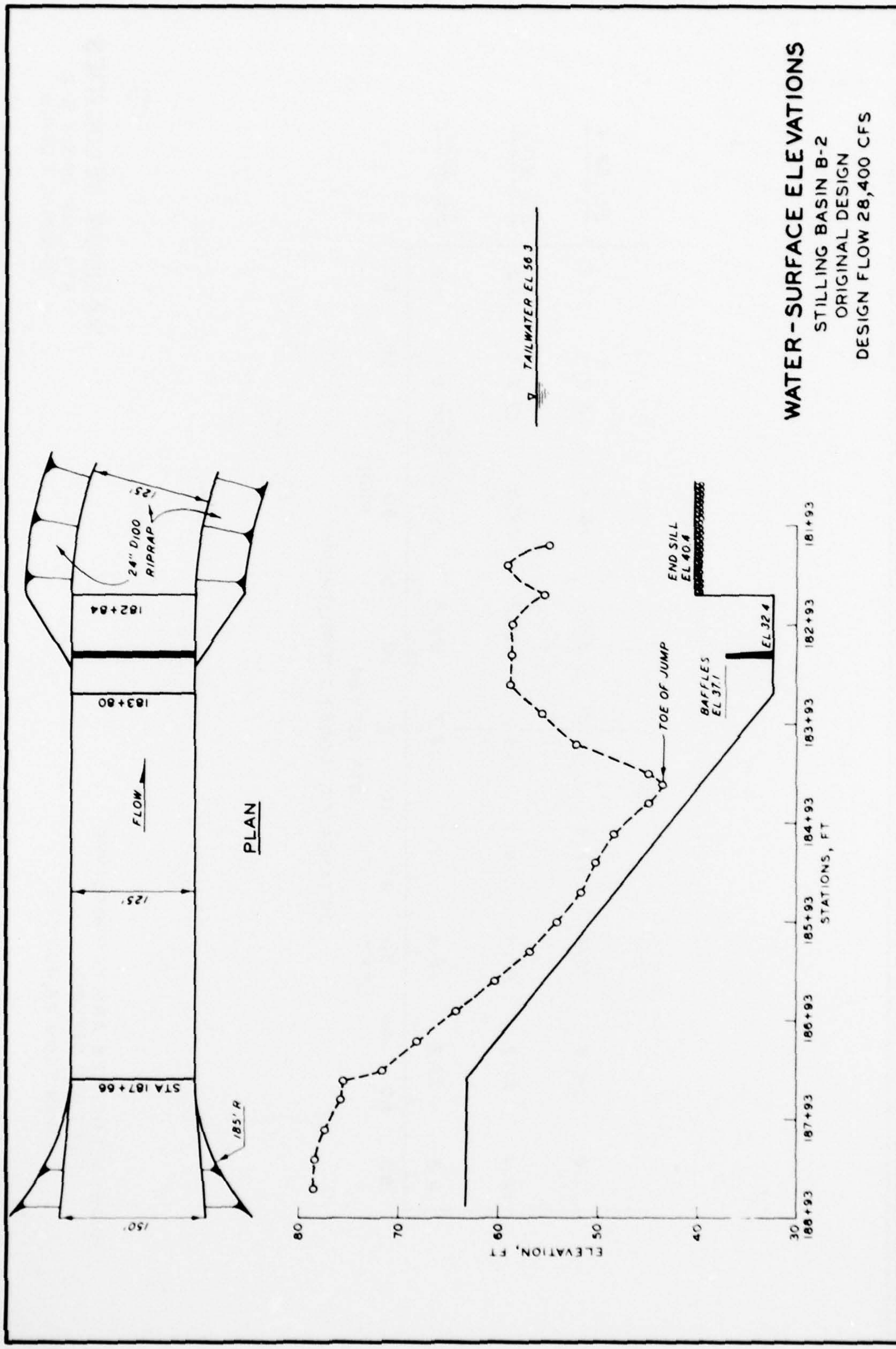
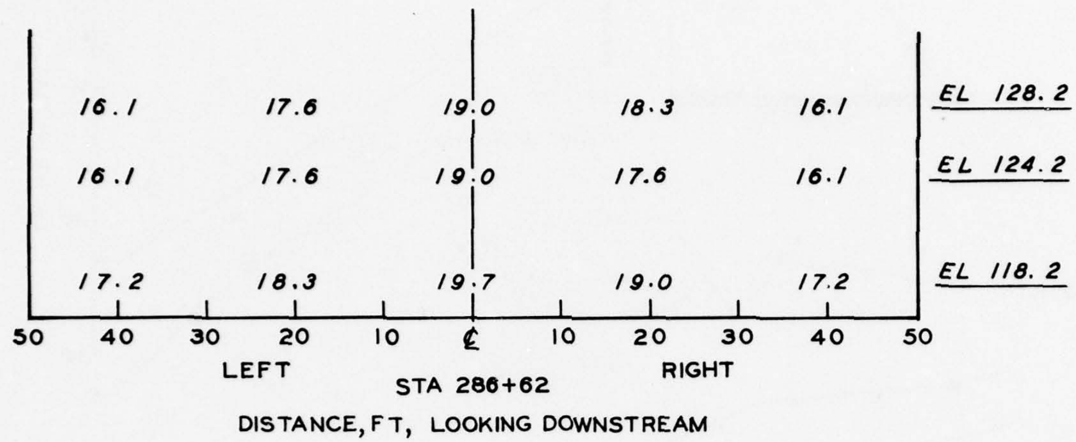
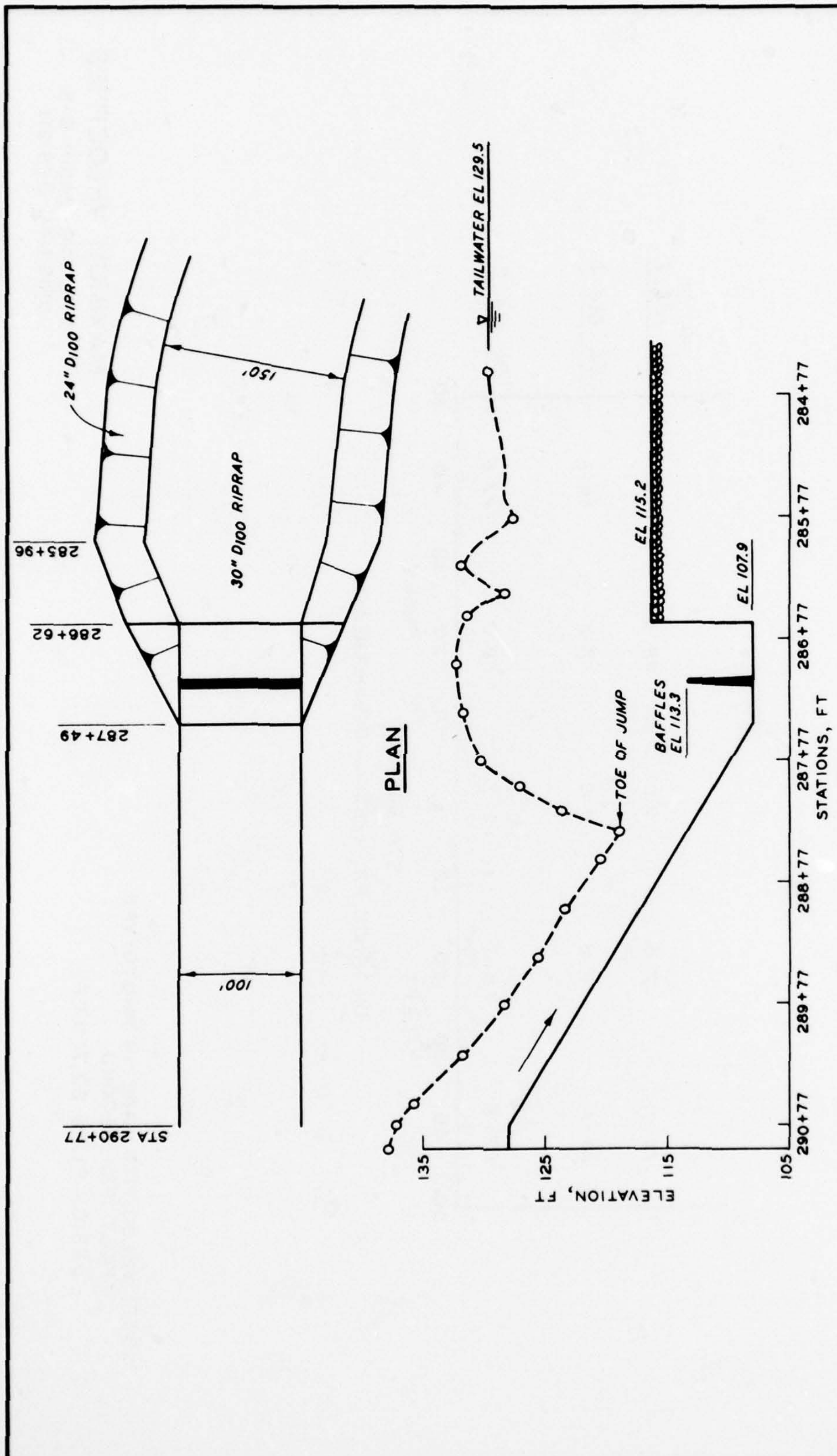

WATER-SURFACE ELEVATIONS
STILLING BASIN B-2
ORIGINAL DESIGN
DESIGN FLOW 28,400 CFS
PLAN
FLOW
150'
125'
125'
185' R
STA 187+66
183+80
182+84
24" D100 RIPRAP
TAILWATER EL 56.3
TOE OF JUMP
BAFFLES EL 37.1
EL 32.4
END SILL EL 40.4
ELEVATION, FT
STATIONS, FT
30
40
50
60
70
80
188+93
187+93
186+93
185+93
184+93
183+93
182+93
181+93

PLATE 32



NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.
DESIGN FLOW 22,700 CFS.

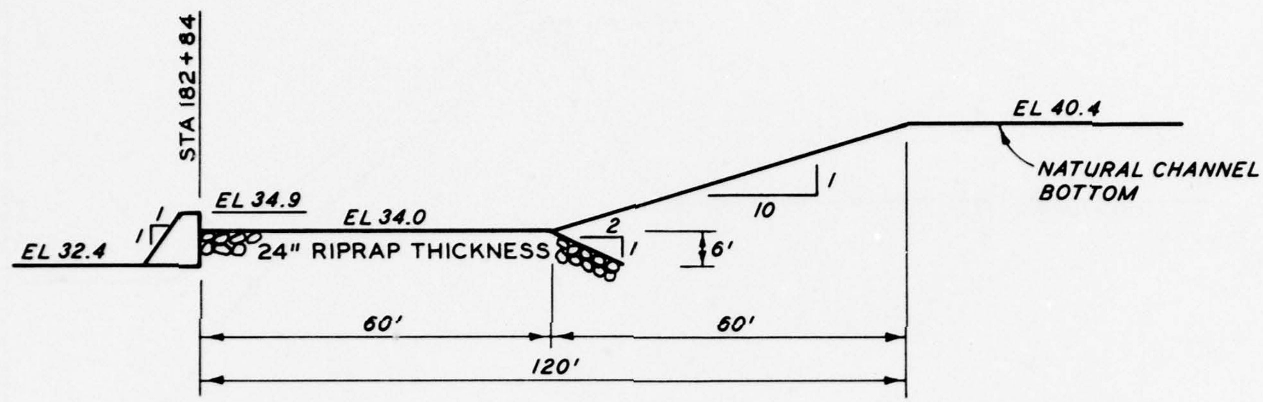
MAXIMUM VELOCITIES
STILLING BASIN B-3
ORIGINAL DESIGN



WATER-SURFACE ELEVATIONS

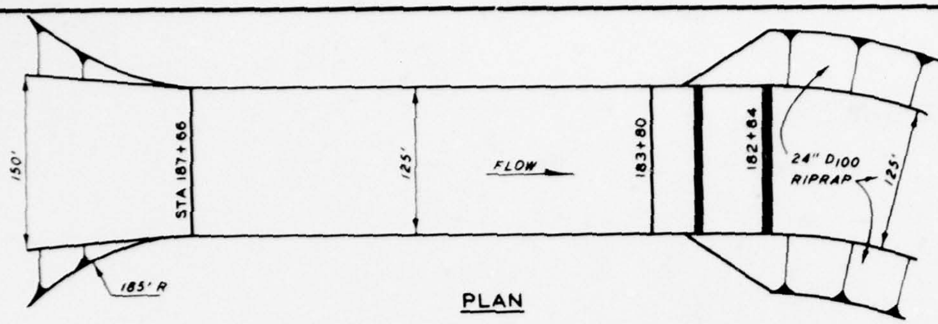
STILLING BASIN B-3
ORIGINAL DESIGN
DESIGN FLOW 22,700 CFS

PLATE 34

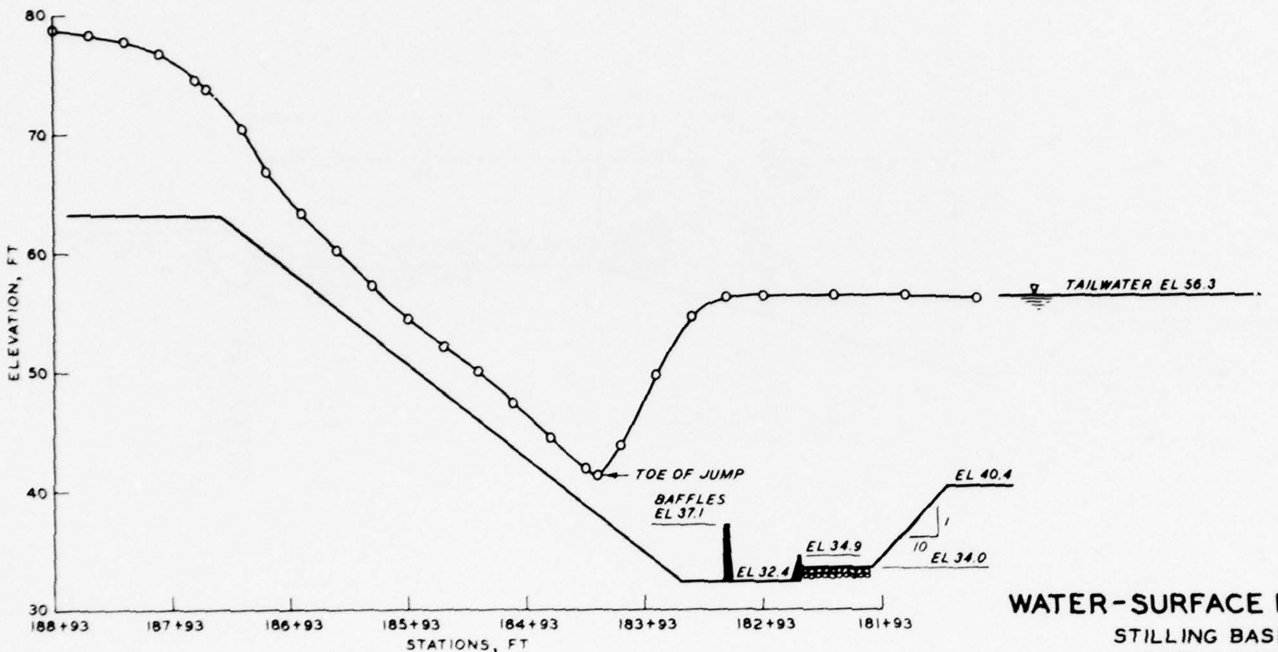


TYPE 2 (RECOMMENDED) DESIGN

STILLING BASIN B-2



PLAN



WATER-SURFACE ELEVATIONS
STILLING BASIN B-2
TYPE 2 DESIGN
DESIGN FLOW 28,400 CFS

EL 50.9	8.8	12.4	14.6	14.6	13.9	14.6	14.6	14.6	10.3
EL 43.9	7.0	9.3	12.4	13.5	13.9	13.9	13.5	9.8	8.7
EL 36.9	4.4	6.2	9.3	11.2	11.2	11.6	9.8	7.6	6.2

60 50 40 30 20 10 ℄ 10 20 30 40 50 60

LEFT RIGHT

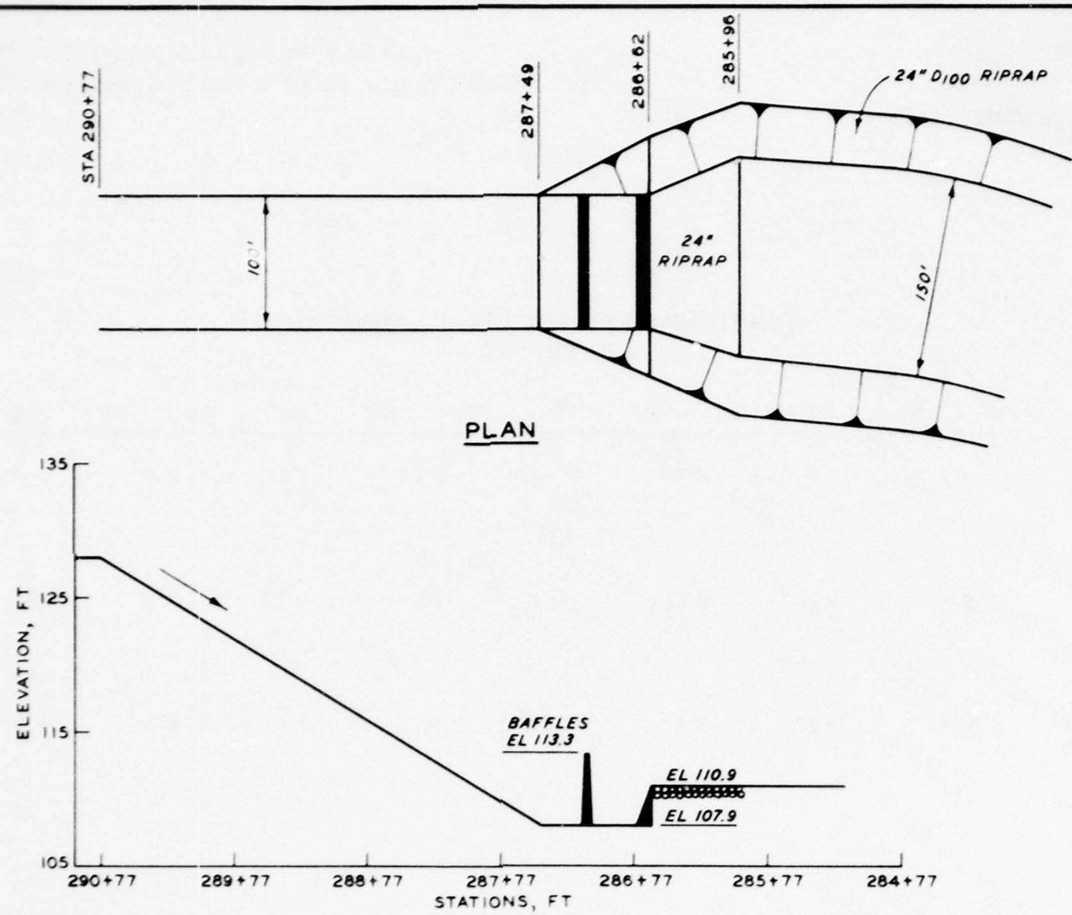
STA 182+84

DISTANCE, FT, LOOKING DOWNSTREAM

NOTE: VELOCITIES ARE SHOWN IN FEET PER SECOND.
PROTOTYPE DESIGN FLOW 28,400 CFS.

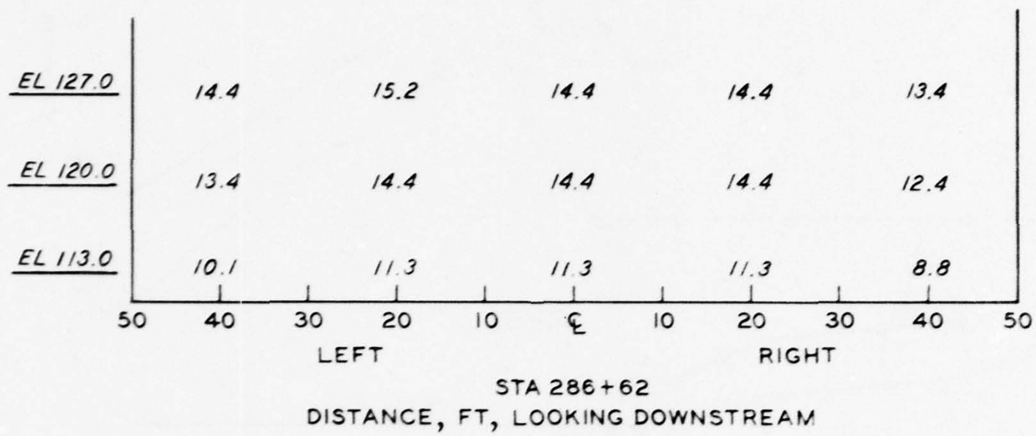
MAXIMUM VELOCITIES

STILLING BASIN B-2
TYPE 2 DESIGN



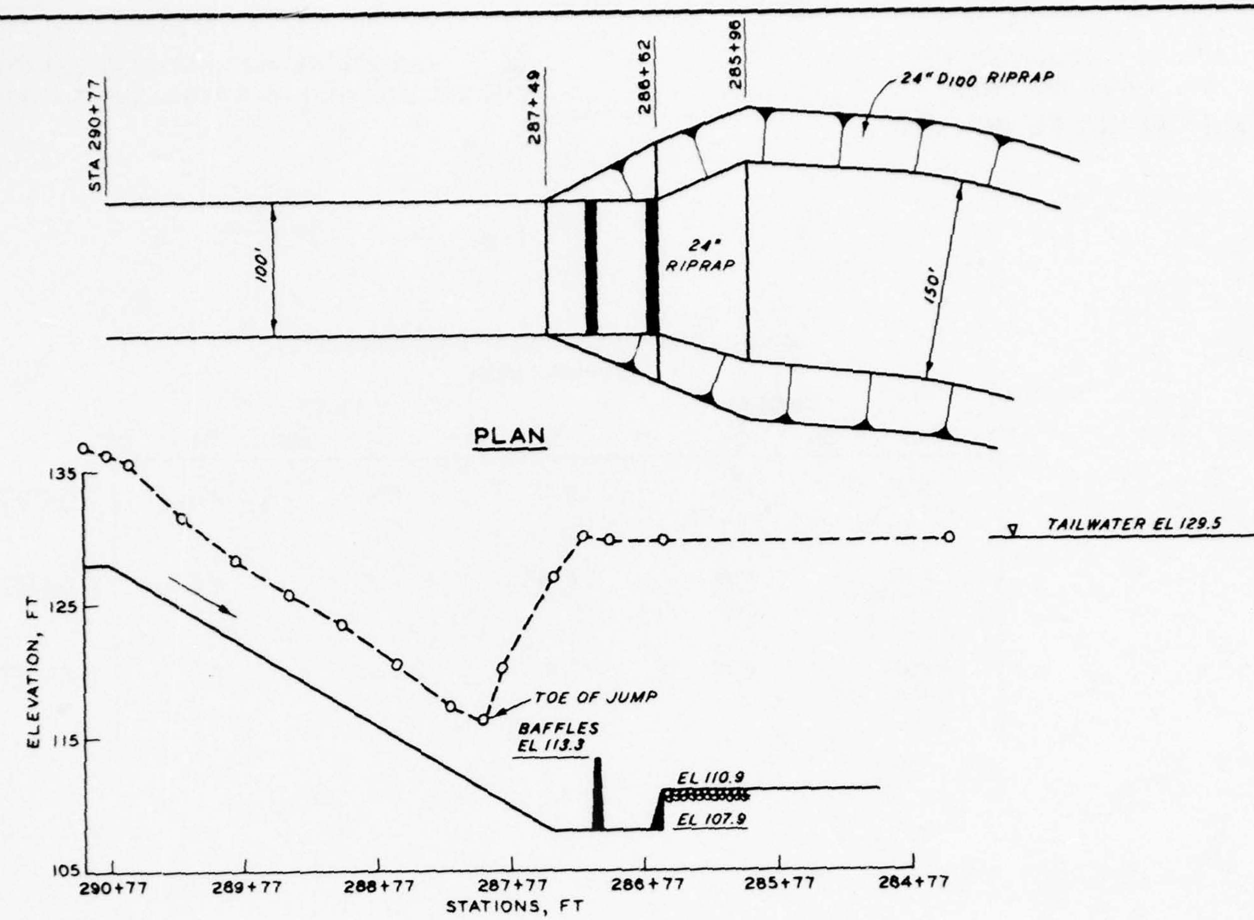
WATER-SURFACE ELEVATIONS

STILLING BASIN B-3
TYPE 2 (RECOMMENDED) DESIGN



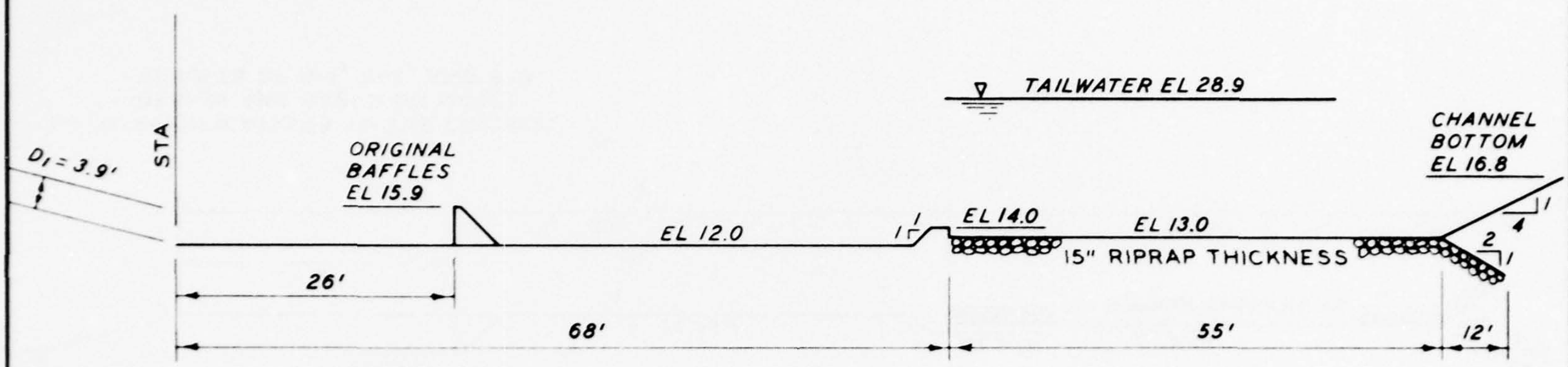
NOTE: VELOCITIES ARE SHOWN IN FEET PER SECOND.
PROTOTYPE DESIGN FLOW 22,700 CFS.

MAXIMUM VELOCITIES
STILLING BASIN B-3
RECOMMENDED DESIGN



WATER-SURFACE ELEVATIONS

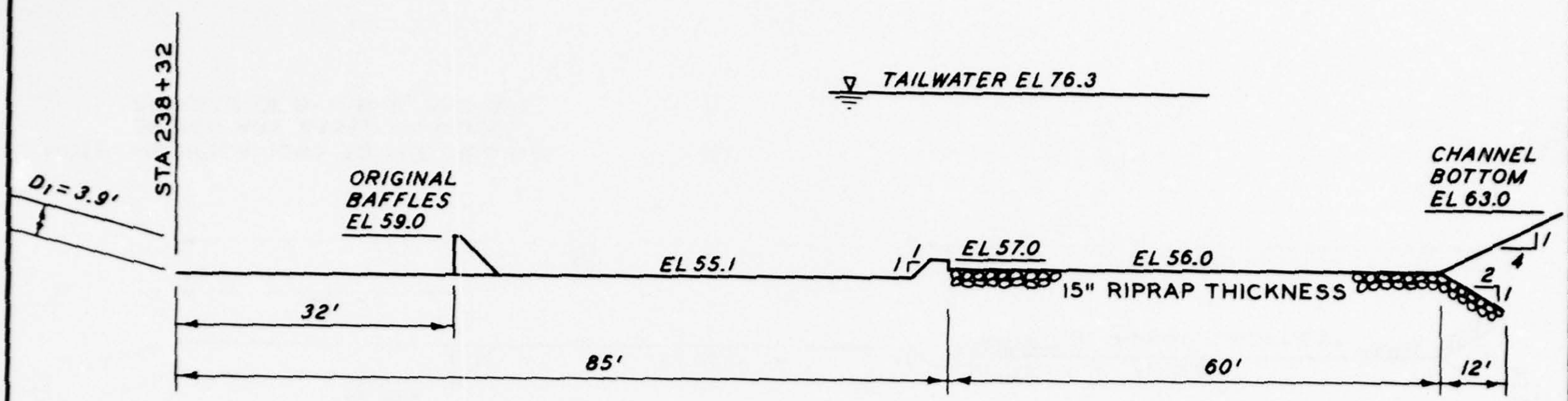
STILLING BASIN B-3
TYPE 2 DESIGN
DESIGN FLOW 22,700 CFS



NOTE: MODIFICATIONS TO THE ORIGINAL DESIGN ARE BASED ON MODEL RESULTS OF B-1, B-2, AND B-3

PROPOSED DESIGN

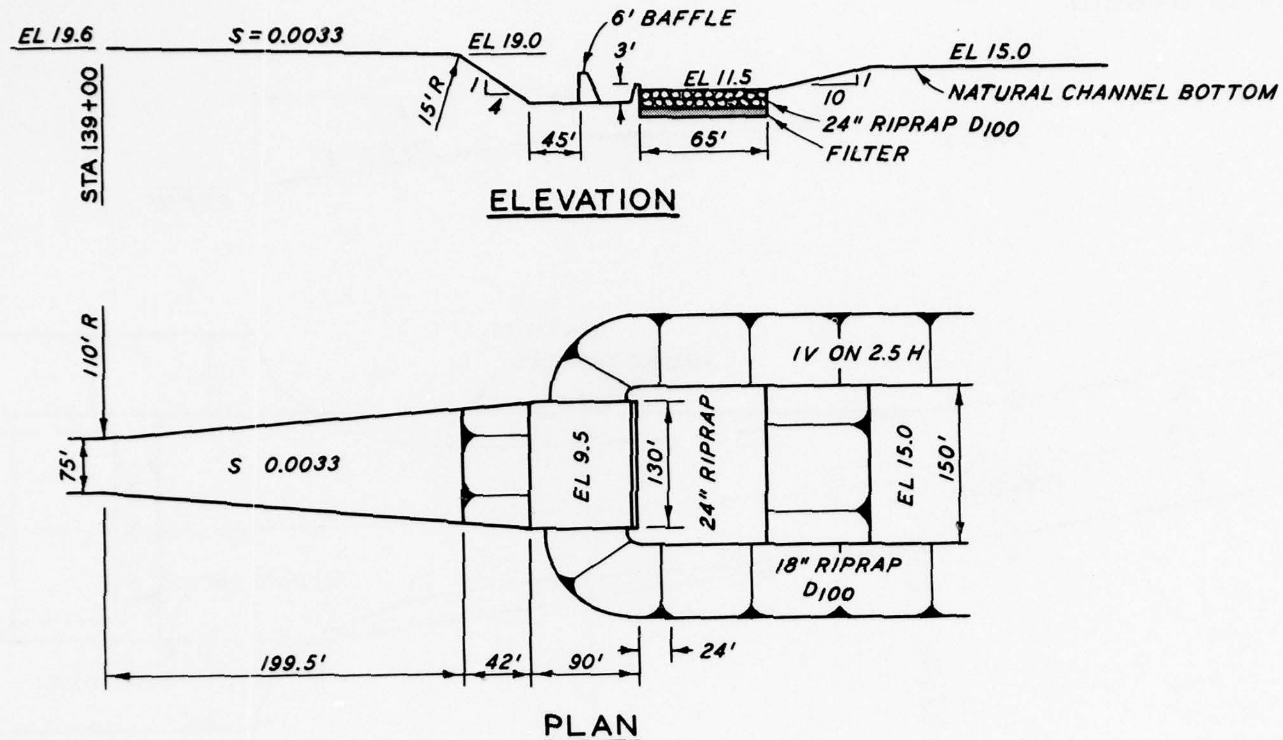
STILLING BASIN P-1



NOTE: MODIFICATIONS TO THE ORIGINAL DESIGN ARE BASED ON MODEL RESULTS OF B-1, B-2, AND B-3.

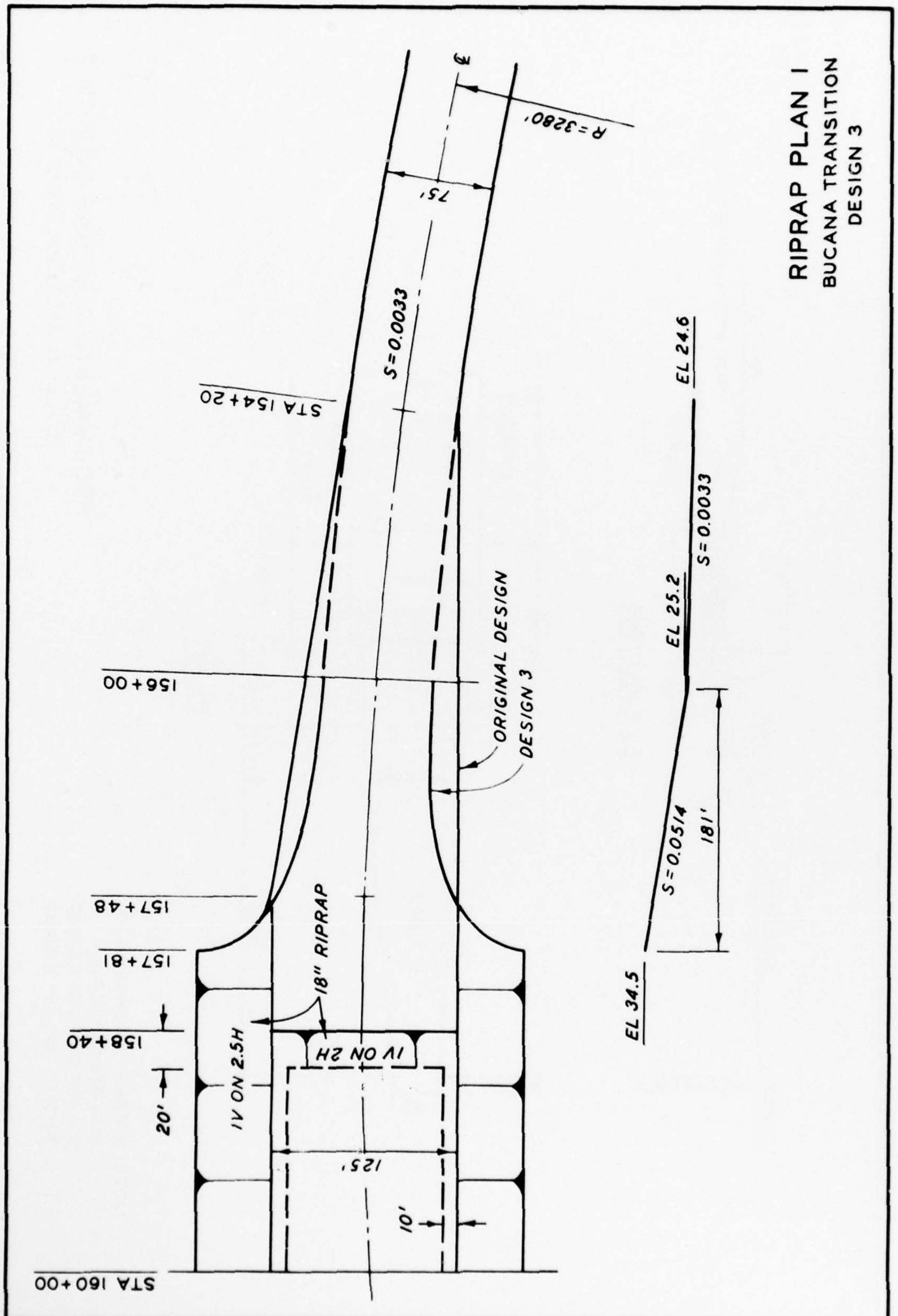
PROPOSED DESIGN

STILLING BASIN P-2



NOTE: RIPRAP THICKNESS, T
MAXIMUM = 1.5 D_{100}
T = 36" FOR 24" RIPRAP
T = 27" FOR 18" RIPRAP

RECOMMENDED RIPRAP DESIGN 7
STILLING BASIN B-1 (TYPE 5)


RIPRAP PLAN I
BUCANA TRANSITION
DESIGN 3
R=3280'
75'
S=0.0033
STA 154+20
156+00
ORIGINAL DESIGN
DESIGN 3
157+48
157+81
18" RIPRAP
158+40
1V ON 2H
1V ON 2.5H
20'
125'
10'
STA 160+00
EL 24.6
S=0.0033
EL 25.2
181'
S=0.0514
EL 34.5